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ELEMENTS

OF

NATURAL PHILOSOPHY

DELINEATED.

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DELINEATED.

BY

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AUTHOR's PREFACE.

IN this Second Edition of the Elements of Natural Philoſophy, I have kept in view the remarks, which were made laſt year, 1753, on the firſt edition; either by the authors of the Literary Intelligence of *Gottingen*, or by a perſon of eminence in *London*, who is pleaſed to honour me with his patronage, and whoſe zeal and regard for the advancement of natural knowledge, have often put me on making a variety of inquiries into phyſical ſubjects. And the more grounded theſe remarks, the more pleaſed have I undertaken to make the amendments pointed out by them.

The original partition of the elements into five heads of ſcience or doctrine I have retained; as agreeably thereto, the doctrine of bodies may be explained with a good degree of order and diſtinctneſs: Nor have I omitted any one of the heads formerly explained. And I have alſo kept to the order they ſtood in, in the former edition, bating in two particular inſtances. Where, firſt, I have added, under the title of *The eighth Part*, from the doctrine of ſolid bodies, in regard to what they have in common with fluids, ſome chapters to the doctrine of fluid bodies, this tranſpoſition ſerving me for a commodious diviſion. Secondly, I have ranged in a different manner the ſeveral heads, which properly come under the doctrine of ſolid bodies. The doctrine itſelf is compriſed in three parts. In the firſt I treat of the earth. In the ſecond, of the ſun: and in the third, of the other celeſtial bodies. The firſt part conſiſts of four ſections. And firſt, under the head of the earth, I come to take a view of what conſtitutes it a mundane body. Secondly, of the viſible and conſtituent parts of the earth. Thirdly, of its atmoſphere. And fourthly, of animated bodies. In the firſt edition not only was this diviſion wanting, but alſo the conſideration of animated bodies preceded that of the earth, ſun and other heavenly bodies. The luminous phenomena of the atmoſphere were in the firſt edition explained in the doctrine of ſolid bodies, under the title *of what ſolids have in common with fluids*. But in the preſent edition explained,

plained, in the firſt part of this doctrine, in the fifth chapter of the third ſection, entitled, *Of the atmoſphere of the earth.*

Beſides theſe alterations, which barely regard the external form or diſpoſition of the book, I have made ſeveral additions: As, in the doctrine of the forces, with which bodies act on each other, I have enlarged the chapters, that treat on the mutual connection of bodies, on the preſſure of fluids, on elaſticity, and on the central forces. In the doctrine of fluids I have given an account of the principal air-pumps, deſcribed a compreſſing-machine; anſwered ſome objections made to the preſſure of the air; inſerted a circumſtantial deſcription of the moſt remarkable thermometers, together with the rules, how to compare their degrees with each other; examined the queſtion, whether fire be a peculiar ſpecies of matter; explained the properties of vapours, the nature of the conſtituent parts of water, and the effects and force thereof in freezing, in ſolutions, in fire and in ſpungy bodies; made an enquiry into the fluidity of quickſilver; and attempted to explain the properties of the electrical matter, and the nature of its operations. To the doctrine of ſolids I have alſo made ſome additions; as for inſtance, with regard to the ductility of gold and ſilver; the properties of earth in particular, the reſolution of gold by the ſolar fire; the origin of ſprings, and the generation of thunder and lightening from the electrical matter of the air. And laſtly, in the doctrine of the ſyſtem of the world I have enquired into what the æther may contribute to the firmneſs of bodies.

CORRIGENDA, in VOL. I.

P. 63, l. 14, *read* and inflating. p. 80, l. 16, for line *read* ſine. p. 83, l. 9, and l. 19, for inciſions *read* rolls. p. 123, l. 8, from the bottom after external, *read* air. p. 138, l. 15, for pure *read* more, p. 158, l. antepenult. and penult. *dele* the, p. 159, l. 9, *read* thermometer made after *Deliſle*'s. *ib.* for which were adjuſted by, *read* the. p. 165, l. 4, for place *read* ſpace. p. 194, l. antepenult. *dele* 8. p. 209, l. 2, for ſmelting of iron *read* melting of ice. p. 223, l. laſt *dele* and. p. 234, l. 5, from the bottom *read* falls. p. 294, l. 10. from the bottom *dele* it. p. 306, l. 1, *read* encaſed. p. 315, l. 7, from the bottom *read* will A therefore. p. 327, l. 5, *read* otherwiſe *inſtead of* other.

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ELEMENTS OF NATURAL PHILOSOPHY.

The Notion of Natural Philoſophy.

§. 1.

PHYSICKS, or *Natural Philoſophy* is the ſcience of the forces, and properties of the bodies, that conſtitute the viſible world.

§. 2. By the ſenſes we attain the knowledge of bodies in a twofold manner. We obſerve either 1. what they own of themſelves, without being put to the queſtion. Or 2. what, on being put to the queſtion, they are made to own; which they otherwiſe refuſe. This latter way of knowledge we call *experiment:* The former ſimply *experience*, and attainable either with, or without art. As well experience as experiment affords that knowledge of bodies, we call *natural hiſtory*, as exhibiting the facts of the corporeal world.

§. 3. The effects, which we diſtinguiſh in bodies by the ſenſes, ariſe from certain cauſes, for inveſtigating which we require certain general propoſitions; abſtracted partly by experience from individual bodies; or partly borrowed from metaphyſicks, which contains the firſt principles of all human knowledge; and principally from mathematics. How we come to general propoſitions, and thoſe of ſervice in natural philoſophy, baron *Wolfius* has ſhewn in his *Uſeful Experiments*, P. 1. §. 17. by that experiment, formerly deſigned to exhibit the four elements by. On putting iron filings into a glaſs, and pouring on them ſucceſſively oil of tartar *per deliquium*, ſpirits of wine, and diſtilled oil of petrol; they remain ſtanding above each other in the order we now mentioned them. And tho' jumbled together, ſoon recover their order again if not further diſturbed. By attending to which, we learn the following truths: *viz.* That petrol is lighter than ſpirits of wine, and ſtill lighter than oil of tartar *per deliquium*: That petrol refuſes mixing with ſpirits of wine and oil of tartar: That there are fluid matters, refuſing mutually to mix, tho' heavier one than the other; and that thus the lighter always remain ſtanding above the heavier. On jumbling together fluid matters that refuſe to mix, they again ſeparate by their gravity alone, and this act of ſeparation happens ſo much the quicker the more the matters refuſe to mix, and the greater their difference of gravity. For, we obſerve firſt the petrol, then the ſpirits of wine, and laſt of all, the oil of tartar *per deliquium* fully to ſeparate. In this act of ſeparating, as well the heavier fluid deſcends, as the lighter aſcends. For any of the petrol remaining behind among the ſpirits of wine in the oil of tartar, riſes thro' the ſpirits of wine up to the other petrol. The ſcience of the cauſes of corporeal things is called the *dogmatical*, but the knowledge of the forces and affections of bodies by experiments, the *experimental phyſicks*, or *philoſophy*.

§. 4. All changes in bodies ariſe from motion: Motion ariſes from certain forces, by which one body acts on another. Bodies are either fluid or ſolid. All fluid and ſolid bodies ſtand together in a certain mutual connection, by which they conſtitute the viſible world. Theſe are the principal points to be explained in natural philoſophy.

The Doctrine of Motion.

CHAP. I.

The firſt Propositions of Motion.

§. 5. HEREBY it is, that the parts of a body come to hang together, or cohere, when they act equally ſtrong on each other.

§. 6. As there is nothing in a body to propel it in any certain direction; its motion, on quitting its place, ariſes from an external cauſe.

§. 7. But to bring a body into motion, the whole of its reſiſtance muſt be overcome; that is, its tendency to continue in a ſtate of reſt muſt be weaker than the tendency of the external cauſe to bring it into motion.

§. 8. In ſo far as a body A ſeeks to overcome the reſiſtance of another B, ſo far A acts on B. What B by the reſiſtance acts on A, is called the *reaction*. Now as B only acts on A, juſt as A acts on B, the action and reaction muſt be mutually equal. And therefore the ſtronger that A acts on B, the ſtronger the reaction of B. A heavy ball lying on an even ſurface, may be put in motion by gently pulling at a thread tied to it. Whereas it remains at reſt, and the thread ſnaps or breaks, on giving a ſmart and quick pull. By the gentle pull you only act on, and overcome the weight of the ball; but by the ſmart and quick jerk, on what, beſides its weight, accrues to the ball, and exceeds the cohesion of the parts of the thread. And thus a body B ſtanding connected with a body C; a body A acting on B, and having no force whereby in general to produce a greater action than is the reaction of the body B; none of the action of the body A will be obſerved on the body C. Lay for inſtance, a quite ſmooth plane of glaſs on a ſmooth, horizontal, unyielding ſurface, and on the plane of glaſs, ſome leaves of a ſoft paper, and on theſe a flat and thick iron plate; and you may ſtrike with a hammer on the plate, and the glaſs plane not break.

§. 9. Each ſeveral action, whereby a body is put in motion, communicates a certain degree of velocity to it; by which in a certain time it deſcribes a certain line, called the *line of direction.*

§. 10. And thus a body moving by one ſingle action, and in its motion ſubject to no change from any external cauſe, goes conſtantly on in the ſame direction, with the ſame degree of velocity. And as a body at reſt, continues in that ſtate, till brought out of it by an external cauſe, §. 6; ſo a body in motion continues its acquired velocity in one and the ſame manner, till an external cauſe produce a change therein. The force by which a body at reſt, ſeeks to perſevere in its ſtate of reſt, is not loſt, while put in motion by another body: But neither receives it from the moving body any actual force which the moving body loſt, to continue in motion. And thus a body in motion, and undiſturbed therein, continues its acquired motion by that very force, by which it ſought to continue in its ſtate of reſt. That force by which a body ſeeks to remain in its ſtate, either of reſt, or of motion, is called the *inertia*, or *vis inertiæ*. And thus we come to learn to diſtinguiſh between body and ſoul. For, by the force or faculty of thinking, the ſoul has a conſtant tendency to change its ſtate: which we cannot aſcribe to the body, as being incapable of two contradictory properties at one and the ſame time. This diſtinction between ſoul and body profeſſor *Euler* has plainly ſhewn in his *Enodatio quæſtionis, utrum materiæ facultas cogitandi tribui poſſit, nec ne? Ex principiis mechanicis petita.*

CHAP. II.

The general Kinds of FORCES and MOTIONS.

§. 11. THAT from which, the action of one body on the other ariſes, is called a *force.* If the action be with motion, the force is called *living,* or an *impulſe:* If without motion, *dead,* or a *preſſion.* To preſſion and impulſe of a certain magnitude, a certain power is aſcribed: But which, as being proportional to the force, has generally the name only of the force.

§. 12. Motion is divided into ſimple and compound; uniform and variable. In the uniform motion, the body ever retains the ſame degree of velocity. In the variable, it is ever changing. The velocity is the ſame, when in equal times equal ſpaces are deſcribed. A ſimple motion is produced by a ſingle force, acting in the ſame direction. But a compound motion by two oppoſite, or by two conſpiring forces, acting in different lines. For inſtance, fig. 1. plate 1. in A E and A F, which include an angle E A F, called the *angle of direction.*

§. 13. A body impelled by two conſpiring forces, whoſe velocities are to each other, as the lines of direction, takes the middle way, the diagonal to a parallelogram, between theſe lines, plate 1. fig. 1. In the parallelogram A E F G, ſuppoſe the line A C F to move to B D H, in the time that the body comes from A to C: at the end of this time the body comes to be in D. Further, ſuppoſe the line B D H to move to E G, in the time that the body comes from D to H; at the end of this time the body comes to be in G; and thus has deſcribed the diagonal A D G. And in this manner a ſhip goes up the ſtream, when drawn on each ſide of it, by men or by cattle. In this compound motion the body thus deſcribes the diagonal A G in the ſame time it would have deſcribed one of the ſides A E or A F apart. And if the compound motion continues the ſame, the velocity ariſing from the conſpiring forces, is to that produced by one of them, as the diagonal A G to the ſide A E or A F, in which a ſingle force acts. *Graveſande* in his *Elementa Phyſices Mathematica*, §. 191, and the Abbe *Nollet* in his *Leçons de phyſique experimentale*, T. II. *Leçon* V. have deſcribed machines for explaining compound motions by. Take, for inſtance, a ſquare board, plate 1. fig. 1. and placing it vertical, faſten a-top from A to E a ſquare rod of metal, on which a pulley may be drawn from E to A. Round the pulley a thread is flung, tied at one end to the nail, which faſtens down the rod at E. At the other end of the thread a weight hangs. When the pulley comes from E to A, the other end, at which the weight hangs, reaches to A. And while the pulley is drawing from E to A, the weight continues to riſe, the thread being faſt at E, and drawn along the length of the rod EBA. The faſtening of the thread at E is to be conſidered as the force, by which the weight is to be drawn up from G to E: But by the force whereby the pulley is drawn from E to A, it has a direction towards GF. So that the weight goes along the diagonal GA. Or, on one end of a board, placed horizontal, ſet a frame, on whoſe upper croſs beam two wings, like thoſe of a door, are ſecured with ſcrews, but ſo as to turn and wind at pleaſure. The under rim of each wing exhibits an arch of a circle, divided into degrees. Above at each wing a hammer hanging perpendicularly downwards, is fixed, which may be pulled up; and falling back, ſweeps along the under rim of the wing. Both wings are ſo placed, as that both hammers in the time they come to their perpendicular poſition in two lines of direction, that interſect each other, ſtrike at the ſame time againſt an ivory ball, lying on the board. And the ball directly takes its courſe along the middle line between the ſaid two lines of direction.

§. 14. With reſpect to the lines in which a body moves, motion is either rectilinear or curvilinear. This laſt is produced by conſpiring forces, and therefore compound: The firſt is either compound, or may be conſidered as ſuch; in regard a parallelogram may be deſcribed about any right line.

CHAP. III.

Of heightening the Forces by Machines.

§. 15. A FORCE is heightened or increaſed, when made capable of performing more than it naturally can of itſelf; and thus either effect in a certain time as much as a greater force in a like time; or, do ſomething more in a ſhorter time than otherwiſe it is capable of.

§. 16. A machine by which a force may be increaſed, is a body in which three points come to be conſidered. On one of them the body reſts; but at both the others, the power and weight are applied. A body has weight, in ſo far as with its gravity it withſtands the force of another. And in ſo far as weight and power by their gravity exert a force, in ſo far they have weight.

§. 17. By gravity a body is impelled to the centre of another in a perpendicular line, drawn from the point of a body, dividing it into two parts of equal weight, and called the centre of gravity. The manner of determining which in the ſeveral kinds of bodies, Baron *Wolfius* ſhews in his *Elementa Mechanicæ*, §. 158—191.

§. 18. Among the heightening machines the leaver ranks firſt, conſiſting of an inflexible line, ABC fig. 2. plate 1. which reſts in ſuch a manner on the point B, as that both the parts AB and BC weigh equal: But at the other two points A and C the weight G and power F are applied.

§. 19. As the lines of direction AI and CH, in which power and weight act, are perpendicular, §. 17. The diſtances of weight and power from the centre of motion, or fulcrum B, are eſtimated by the perpendicular lines BA and BC, which may be drawn from the fulcrum B of the leaver to the lines of direction AI and CH.

§. 20. With regard to the inflexible line, of which the leaver conſiſts, the leaver is divided into the *rectilinear* and *curvilinear:* And with regard to the fulcrum, into the *heterodromous*, and *homodromous leaver*. In the *heterodromous*, or leaver of the firſt kind, the fulcrum B ſtands between the points of weight and power. In the homodromous, or leaver of the ſecond and third kinds, without ſide both theſe points. A full explication of the curvilinear leaver, M. *George Frederick Barman*, has given in his *Diſſertatio Mathematica de Vectibus curvilineis*, publiſhed in 1737.

§. 21. In the heterodromous leaver the power F and weight G are of equal weight, when the power F is to the weight G, inverſely as the diſtance AB of the weight to the diſtance BC of the power, fig. 2. plate 1. For the lines CH and AI, in which power and weight have a conatus to fall, paſs thro' the centre of their gravity. And thus as well power as weight acts to right and left with equal weights. Suppoſing F to be one pound, it acts equally ſtrong from 7 to 6 and 8: Suppoſe G to be three pounds, it acts with three half pounds from A to 6, and with three half pounds from A to E. From E to B are four equal parts, and from D to B alſo four equal parts. Now as power and weight, by means of the leaver, unite their effects in the fulcrum B, they are both together to be conſidered as one body KL, which reſts in the centre of gravity M, and weighs equally both to right and left. As weight and power unite their effect, that is, their gravity in the fulcrum, this laſt is called the *common centre of gravity*. And ſeeing F : G : : AB : BC, by the rule of four geometrical proportionals, the product of F and B C is equal to that of G and A B. Now F is the power, and BC its diſtance from the fulcrum B; and G the weight, and A B its diſtance from the ſame point or fulcrum. And thus the forces of bodies, that weigh equally at a leaver, are eſtimated by the product of their maſſes into the diſtances from the fulcrum; this product is uſually called the *momentum* of the weights.

§. 22. Two forces at 5 and 6 on a heterodromous leaver are to each other inverſely as their diſtances B 6 and B 5 from the fulcrum. Let AB = B 5, and B 6 = 2 B 5: Hang on two pounds in A, and in 5 two pounds alſo: And thus the leaver ſtands at reſt. Hang in A two pounds, and in 6 one pound: and thus too the leaver is at reſt, §. 21. Now the two pound power at 5 is to the one pound at 6, as the double diſtance B 6 is to the ſingle B 5.

§. 23. And thus in the homodromous leaver the weight is to the power, inverſely as the diſtance of the power to the diſtance of the weight, fig. 2. plate 1. Taking B for the point of motion or fulcrum of the leaver, one of either powers at 5 and 6 may be conſidered as a weight, ſuſtained by the other. Now as the fulcrum B ſtands without the points 5 and 6, at which power and weight are applied: So is the leaver, at which they hang, homodromous, §. 20.

§. 24. As the leaver is not reſolvable into other machines, it ranks among the ſimple kind, and that as the firſt; the ſecond place the pulley takes; the third the wheel; the fourth the ſcrew; the fifth the wedge. But theſe four ſimple machines are only heterodromous leavers, in which the centre of motion, and the points of power and weight, on account of the different circumſtances, ſtrike not the eye ſo diſtinctly as in the leaver; which is repreſented ſimply as a bare line with thoſe three mentioned points. The pulley fig. 8. plate 2. is a circle or ſheeve B F A E L, about which goes a rope, at which weight and power may be applied. At C is the centre of motion of the ſheeve. At the one end A the power acts; at the other B the weight. So that the line B C A exhibits a heterodromous leaver. But as the points A and B are equidiſtant from the centre C, ſo in order to ſuſtain the weight in a ſingle pulley, a power equal thereto is neceſſary. But if on the other hand a number of pulleys be combined in ſuch a manner, as that the effect of the weight is divided or ſhared out by the rope drawn about them; the diſtance of the power increaſes with the number of the pulleys: And thus the power is increaſed, which it is not in the ſingle pulley. Such a combination of pulleys is called a *polyſpaſtus*, or a tackle of pulleys. A wheel is a circle AFBLE faſtened on an axis IGH, which at the ſame time with the axis may be moved round their common centre C, fig. 8. plate 2. If the weight is applied to the axis at the point G, and the power to the wheel at the point B, power and weight act on each other by means of a heterodromous leaver; and thus the power at B is to the weight at G, as the radius of the axes CG to the radius of the wheel BC. For, *that* is the diſtance of the weight, and *this* the diſtance of the power from the centre C. The greater, therefore, the radius of the wheel, the leſs power is requiſite for one and the ſame weight. But if the weight at the wheel, and the power be brought nearer the centre; when, for inſtance, a wheel is turned by a crank, the power to be applied, muſt be greater than the weight to be moved. If ſeveral wheels are combined together, ſo as that one always plays in, or takes another, and the weight is applied to the axis of the laſt wheel, and the power to the firſt wheel; power and weight are in the compound inverſe ratio of the radii of the axes, and of the radii of the wheels: Or, the power is to the weight inverſely as the product of the radii of the axes to the product of the radii of the wheels. Suppoſe three wheels, and at the axis of the laſt 6000 pounds are hung; and ſuppoſe the radius of this third wheel to be to the radius of its axes, as 6 to 1. Now in order only to ſuſtain the 6000 lb. by this third wheel, a power of 1000 lb. would be neceſſary. For, 6 : 1 : : 6000 : 1000: and thus the ſecond wheel has 1000 lb. to ſuſtain. If its radius is to that of its axis, as 10 to 1, you need only apply to the ſecond wheel a power of 100 lb. For, 10 : 1 : : 1000 : 100, And thus you have to ſuſtain with the firſt wheel only a weight of 100 lb. And if its radius is to that of its axis, as 10 to 1, the firſt wheel requires only a power of 10 lb. For, 10 : 1 : 100 : : 10. And this very reckoning comes out, on multiplying the radii of the wheels and alſo the radii of the axes together; the product of the ſaid radii of the wheels being 600, and the product of thoſe of the axes being 1 : and therefore 600 : 1 : : 6000 : 10. Or, 1 : 600 : : 10 : 6000.

Wedge and ſcrew are inclined planes: On which in order to ſuſtain a weight, the power muſt be to the weight, as the height of the plane AB to the length BC fig. 9. plate 1. Power and weight act on the inclined plane againſt each other juſt as at a leaver. In order to explain this, fig. 1. plate 1. may ſerve. If the weight be drawn from G to A, and there ſuſtained; it is the very ſame thing as if it were in

E, and ſuſtained by a power acting in the line EA. For, every where in the horizontal line FHG it may have its centre of motion. Now as in E it is as diſtant from that line as in A; ſo EG is the diſtance of the weight from the centre of motion G. The line AE, in which the power acts is parallel and equal to the baſe line FG. And ſo you are to conſider FG as the diſtance of the power from the centre of motion G; FGE therefore exhibits a heterodromous leaver. And thus the power in F or A is to the weight in E, inverſely as the diſtance EG of the weight to the diſtance FG of the power. EG is the height, and FG the length of the inclined plane. So that on it, the power is to the weight, as the height to the length of the plane.

A *ſcrew* is an inclined plane carried round an axis. The axis, round which it is carried, is called the *ſpindle*. If the threads are internally on the ſurface of an excavated axis, the ſcrew is called a *ſcrew-nut*. The diſtance of the ſcrew-threads is the height, and the periphery of the ſcrew, the length of the inclined plane, thus carried round. So that in the ſcrew the power is to the weight as the diſtance of the ſcrew-threads to the periphery of the ſcrew. When the ſcrew takes a ſtar-wheel, it is called the *endleſs ſcrew*, with only three threads. The cogs in the ſtar-wheel muſt be cut by the ſcrew-threads, that is, by the angle of the ſpindle. On each turn of the ſcrew, a cog is turned in the ſtar-wheel.

In the caſe of the ſingle wedge, which is a ſingle inclined plane, the power is to the weight as the thickneſs of the wedge to its length: And in the caſe of the double wedge, which is a double inclined plane, the ſame proportion holds. How this may be diſcovered by experiment, *Graveſande* ſhews in his *Elementa Phyſices*, §. 120, and the Abbè *Nollet* in his *Leçons de Phyſique*, T. III. *Leçon* IX. Sect. 1. *Experiment* II.

CHAP. IV.

Of the Rubbing or Friction, and the Reſiſtance ariſing in MOTION.

§. 25. AS on the ſurface of a body certain parts project beyond the others, ſo the roughneſs thence ariſing weakens the motion of the body, which is to be propelled on ſuch a ſurface. The reſiſtance ariſing from this roughneſs is called the *rubbing* or *friction*; whoſe degree of ſtrength or intenſeneſs is to be ſought for partly from the quantity of the roughneſs, partly from the quantity of the ſurface, on which the body moves, partly from the preſſion with which the body acts on the ſurface. How various it is in machines, the experiments made with the *tribometer* ſhew, deſcribed by *Muſchenbroeck* in his *Inſtitutiones Phyſicæ*, chap. ix. *de attritu machinarum*, where he relates the many experiments he had made therewith. It is a roller, which may be placed horizontal, with its two well poliſhed gudgeons in ſockets, which may be lodged in pillars and again taken out. And ſockets of all kinds of metals, and of different ſorts of wood are uſed for the purpoſe, in order to obſerve the difference of rubbing in thoſe ſeveral kinds of materials. Round the roller a ſtring is ſlung, at whoſe ends two equal weights hang. On the one you lay ſome of the parts or ſubdiviſions of a pound ſo long, till this weight ſinks down and the other riſes. The parts of the pound added ſhew the degree of the rubbing.

§. 26. If a body is propelled in a fluid; in regard to the reſiſtance we are to conſider partly the coheſion of the parts that are to be ſeparated; partly the ſluggiſhneſs and gravity of the oppoſing matter; partly the quantity of the ſpace through which the body moves; partly the magnitude and velocity of the moving body. The more ſluggiſh the fluid, the heavier and denſer it is. But the greater the denſity or gravity, the greater the reſiſtance. The greater the ſpace through which the body moves in a fluid, the greater the number of the particles which it is to propel, and thus too the reſiſtance the more increaſed. And in like manner it will be always greater, the greater the force with which the moving body acts on the fluid: For, the ſtronger the body acts on the fluid, the ſtronger the fluid re-acts. Alſo a body muſt undergo a greater reſiſtance than another, if its ſurface exceeds that of the other. For, the greater its ſurface, the greater number of parts it muſt propel.

By the reſiſtance of a fluid, a body is weakened in its motion, or retarded. Reſiſtance and retardation are mutually equal, when conſidered in one and the ſame body. For inſtance, a ball ſhot through the air; the decreaſe of velocity, or the retardation of the ball is ſo great, as is the reſiſtance of the air. On the other hand, in two bodies different retardations may ariſe by one and the ſame reſiſtance. As ſuppoſe we let a ball of lead and a ball of clay, both of equal magnitude, go into water with an equal velocity in one and the ſame direction: Both balls undergo an equal reſiſtance, as an equal quantity of water makes reſiſtance to both. But as the ball of lead is denſer, or contains more matter, with which it ſtrikes, and conſequently is ſtronger than the ball of clay; ſo the velocity of the ball of lead, in the time that the ball of clay loſes a part of its firſt velocity, comes to loſe a leſs part. By ſo much therefore, as the denſity of the ball of lead exceeds that of the equal ball of clay, by ſo much leſs the motion of the ball of lead is retarded in the water. The peculiar laws of reſiſtance and retardation, which bodies undergo when moving in fluids, *Graveſande* explains in his *Elementa Phyſices, lib.* ii, *c.* 6. *Nollet* in his *Leçons de Phyſique*, T. I. Leçon III. Sect. 3. art. 1. and M. D. *Jacob Adami* in his *Specimen hydrodynamicum de reſiſtentia corporum in fluidis motorum*, which in 1752 gained the prize propoſed by the royal academy of ſciences at *Berlin* for examining this ſubject.

If the fluid moves in one and the ſame direction, with a body moving therein, and with a like velocity, it retards not at all the motion of the body. But if ſlower than the body moving therein, it retards the body a little. The nearer its degree of ſlowneſs approaches to a ſtate of reſt, the nearer its reſiſtance approaches to the reſiſtance which it cauſes in its ſtate of reſt. And thus if it moves againſt the body, its reſiſtance is greater than when fully at reſt. *De la Hire* in the *Memoires* of the royal academy of ſciences at *Paris*, has attempted to inveſtigate the power neceſſary to move ſhips as well in ſtanding as in running water.

The motion of a body which either rubs, or is retarded in a fluid, muſt therefore at length ceaſe.

CHAP. V.

General PROPOSITIONS of velocity or celerity.

§. 27. IF the times, which two bodies moving uniformly take to run in, are mutually equal; the celerities of the bodies are to each other as the ſpaces run over. For inſtance, if A in one ſecond runs over one foot, and B in one ſecond four feet; the celerity of the body A is to that of the body B as 1 to 4.

§. 28. But if the ſpaces are mutually equal, the celerities are to each other inverſely as the times, which the uniformly moving bodies take to run in. For, in leſs time the motion is performed in an equal ſpace, the greater the celerity. As, ſuppoſe A to run over a ſpace of eight feet, and B in like manner a like ſpace; and the time in which A does it to be one ſecond, and that in which B, four ſeconds: As that thus A is four times ſwifter, that is, the celerity of A is to that of B, inverſely as four ſeconds, which B takes, to one ſecond, in which A deſcribes the ſpace. And thus the celerities of two bodies are in general in the compound ratio of the direct ratio of the ſpaces, and the inverſe ratio of the times; that is, the celerity of the body A is to the celerity of the body B, as the product of the ſpace, which the body A runs over, and of the time which the body B takes; to the product of the ſpace, which the body B runs over, and of the time which the body A employs. And thus according to the foregoing example, the celerity of the body A is to that of B, as 32, the product of 8, the ſpace run over by A, and of 4, the time which B has taken; to 8, the product of 8, the ſpace accompliſhed by B, and of 1, the time which A has employed. But 32 is to 8, as 4 is to 1.

§. 29. As a ſingle time and a ſingle celerity muſt give a ſingle ſpace; ſo a double time and a double celerity muſt give a fourfold ſpace. And thus in uniform motions we find the ſpace, upon multiplying time and celerity together: As a point in the periphery of the earth's equator, running over two hundred and twenty-five german miles in an hour; ſuch is the celerity of that point. And therefore in twenty-four hours, the time in which the earth revolves about her axis, this point will accompliſh a ſpace of five thouſand four hundred german miles.

§. 30. As therefore the ſpace is a product, and time and celerity its factors, you find the celerity of a body moving uniformly, on dividing by the time the ſpace run over: As dividing 5400 by 24, you find the celerity of a point in the periphery of the earth's equator to be 225, that is, it performs ſo many miles in an hour.

§. 31. If the weight A, fig. 4. plate 1. at a leaver A C B, is raiſed by the power B, the celerity of the weight A is to that of the power B, as the diſtance A C of the weight, to the diſtance B C of the power: For, thoſe diſtances are radii of concentrick circles: And in ſuch, the arches A a and B b are to each other, as the ſaid radii A C and B C. But as A a, the ſpace run over, is to the ſpace run over B b, ſo the celerity of the weight A to that of the power B, §. 27.

§. 32. From this it appears, that in the five ſimple organs you muſt employ ſo much the more time, the greater the weight, which is to be moved by a ſmall power. As if in the ſaid leaver, the ſpace A a is to the ſpace B b, as 1 to 3; and if the power, which raiſes the weight through the ſpace A a, deſcends through the ſpace B b in a ſecond; you will require three ſeconds, in order to raiſe the weight at this leaver by means of this very power, through a ſpace as great as B b. The ſlower a weight moves at a leaver, the quicker the power, §. 27. By the ſimple machines or organs, §. 24, as the heterodromous leavers, a power is ſo ordered, as to have a certain degree of velocity, whereby what it wants in weight is compenſated in force. To this head belong *M. Amoutons*'s reflections on the force of machines, publiſhed in the *Memoires* of the royal academy of ſciences at *Paris*.

CHAP. VI.

Of the MOTION of falling, aſcending and projected Bodies.

§. 33. AS a falling body above our earth at the height at which an experiment may be made, is almoſt conſtantly propelled by one and the ſame degree of gravity; ſo in the fall it acquires ſtill greater degrees of velocity, which are equal to the times. Such an increaſing motion is called uniformly accelerated. The velocity of a falling body is thus, in a ſingle time, ſingle; in a double time, double; in a triple, triple; in a quadruple, quadruple, &c.

§. 34. And thus if nothing withſtands a falling body, and if the reſiſtance is inconſiderable; the ſpaces which it accompliſhes in different times by its fall, are to each other, as the ſquares of the times or velocities; and the ſpaces increaſe, as the odd numbers, 1, 3, 5, 7, &c. do. For, we find the ſpace on multiplying the time by the velocity, §. 29. Now in uniformly accelerated motion the velocity is as the time, §. 33. And if the velocity be multiplied by the time, it is all one as if the time were ſquared, or multiplied by itſelf. Call the ſpace S, the time T, and the celerity C. And thus multiplying 1 T by 1 C, the ſpace in the firſt inſtant or moment is equal to 1 S: But multiplying 2 T by 2 C, the ſpace in two moments is = 4 S: And multiplying 3 T by 3 C, in three moments the ſpace is = 9 S. But the number 1, 4, 9, are the ſquares of the times, or celerities, 1, 2, 3. On deducting the firſt of the ſaid ſquare numbers from the ſecond, and this from the third, and in general, the next proceeding from the following, there come out the odd numbers, 1, 3, 5, The demonſtration may be illuſtrated by means of a rectangular triangle, in which the equal parts of the line AB fig. 5. plate 1. denote the times of the fall; and the lines 1 d, 2 c, 3 f, BC, the celerities; and the triangle, the ſpace deſcribed by the falling body. For the triangle A 1 d is to the triangle A 2 c, as the ſquare of the ſide A 1 to the ſquare of the ſide A 2; or, as the ſquare of the ſide 1 d to the ſquare of the ſide 2 c. *Huygens* found, that a body, whether heavy or light, at no great diſtance from the ſurface of the earth, accompliſhes in the firſt ſecond of its fall a height of 15 $\frac{1}{12}$ *Paris* feet. The demonſtration Baron *Wolfius* gives in his *Elementa Mechanicæ*, §. 473.

§. 35. And thus in the caſe of bodies falling freely, the times in the different ſpaces of the fall are as the ſquare roots of the ſpaces. And thus the time in a quadruple ſpace is to that in a ninefold ſpace, as the ſquare root of 4 to the ſquare root of 9; that is, as 2 to 3. The truth of this propoſition, in *Galileo*'s manner, who firſt made it known, and deſcribed it in his third dialogue *de motu*, may be eſtabliſhed by an experiment; with letting an ivory ball run down a well poliſhed tube on an inclined plane, which may be elevated by the ſquares of the times, 1, 4, 9, 16, 25 inches; and obſerving the times, in which at each height it has finiſhed its courſe, by a pendulum.

§. 36. And therefore light and heavy bodies fall equally ſwift in vacuo, or accompliſh equal ſpaces in equal times. For, if a light body A falls through nine feet, and another heavier body B in like manner through nine feet; the ſquare roots of their ſpaces, and conſequently too their celerities are mutually equal. If, for inſtance, a pound of lead falls, it is the ſame thing, as if thirty-two ſingle loths or half ounces began to fall at once. And thus the pound of lead reaching the bottom, is the ſame thing, as if thirty-two ſingle half ounces reached it at the ſame time. And as thus each half ounce apart falls as quick as the other; ſo alſo each half ounce apart falls as quick, as thirty-two half ounces, which begin to fall at the ſame time; and conſequently as quick as a whole pound.

§. 37. The action of a body in motion ariſes partly from its maſs, or quantity of matter; partly from its velocity. For, without maſs it cannot be a body, and without velocity it cannot move. In order therefore to inveſtigate the quantity of the action, produced by a body in motion, we are to conſider the quantity of its maſs and the quantity of its velocity. And as no velocity is conceivable without time; ſo in conſidering the quantity of the action produced by a body in motion, we are not to forget in what time the action was accompliſhed. Suppoſe two equal holes A and B ſtruck or bored through a board, every where equally thick; the one A in ten, the other B in ſixty ſeconds. Without diſpute, the action, by which the one A is made, is greater than the action, by which the other B is produced.

§. 38. By the action which a body in motion produces, we come to know its force and power, §. 11. And hence, inſtead of the term, *action*, it is common to uſe the terms, *force* and *power*. The forces of bodies in motion are living forces, §. 11. And thus two bodies having equal maſſes, and moving with different celerities, their living forces are as their celerities.

§. 39. If therefore two bodies of unequal maſſes, as A of one pound, and B of four pounds, move equally ſwift; their living forces are to each other, as their maſſes: As the force A is to the force B, as 1 to 4.

§. 40. And thus if two bodies A and B of unequal maſſes move with unequal velocities, their living forces are to each other as the products of their maſſes and velocities: As let two yielding balls A and B, whoſe velocities are mutually in the inverſe ratio of their maſſes, run againſt each other; and A with one pound of maſs to have two degrees of velocity, and B two pounds of maſs with one degree of velocity; after the ſhock the two balls come to reſt together; and thus they have acted on each other with equal forces, the product of the maſs and velocity of the one ball being equal to the product of the maſs and velocity of the other.

'Tis thus *Deſcartes* in his *Principia Philoſophiæ*, P. 2. §. 36. And *Newton* in his *Principia Philoſophiæ naturalis*, Defin. 2. determine the quantity of the motion. Whereas *Leibnitz* in a writing, publiſhed in the *Acta Erudit. An.* 1686, and entitled, *Brevis demonſtratio erroris memorabilis Carteſii, &c.* eſtimates the living forces by the products of the maſſes of the moving bodies and the ſquares of their velocities. As if a body A be four pounds in maſs, and a body B one pound; and A falls one foot and B four feet; A by the fall gains a force to riſe again one foot, and B four feet; as will appear from §. 42. As thoſe forces act no further after reaching the ſaid heights; ſo the living force of the body A is to that of the body B, as the product of the maſs 4, and the height 1, to the product of the maſs 1 and height 4. Now as theſe heights 1 and 4 are equal to the ſpaces, through which the bodies fell, and in which by the fall they acquired the ſaid forces to riſe or aſcend with: So theſe heights are to each other, as the ſquares of the velocities, which the falling bodies acquired in the ſaid heights or ſpaces, §. 34. From this *M. Leibnitz* concludes, that the force of the body A is to that of the body B, as the product of the maſs 4 and the ſquare of the velocity 1, to the product of the maſs 1, and ſquare of the velocity 2: And that thus the living forces of the bodies A and B are mutually equal; as one and the ſame force is neceſſary to raiſe a fourfold weight through a ſingle height, as to raiſe a ſingle weight through a fourfold height. If the bodies A and B are metal balls of equal diameters,

ameters, and fall through the ſaid heights into ſand or ſoft clay; they make equal pits therein. This experiment is ſuppoſed to eſtabliſh the living force of the ball B to be as great as the living force of the ball A. But this can by no means be admitted, as profeſſor *Kraft* ſhews in his *Prælectiones in Phyſicam Theoreticam*, §. 95—100. The quantity of a living force is to be eſtimated by the quantity of the action or effect produced by it, §. 38. But in that we are to conſider the time, in which the effect was accompliſhed, §. 37. The pits which were made in the ſand or clay by the balls A and B, are indeed mutually equal; but not compleated in equal times. The ball B is ſwifter in the fall than the ball A; and thus makes its pit in a ſhorter time than the ball A. Much leſs can we admit, that the forces with which the four-pound body A can aſcend one foot; and the one-pound body B, four feet, are mutually equal; as body B takes ſo much longer time to aſcend in than A, as it took a longer to deſcend in than A. For, if A falls one foot, but B four feet; B in falling takes double the time, §. 35.

§. 41. As the cauſe of gravity, which accelerates uniformly the velocity of the falling body, weakens the motion of the perpendicularly aſcending; ſo this motion uniformly decreaſes: And the decreaſe of the ſpaces ariſes according to the odd numbers, 7, 5, 3, 1.

§.

§. 42. If ſuch a body in the firſt moment aſcends through a ſpace, denoted by 7; in the ſecond it aſcends through a ſpace 5; in the third through a ſpace 3; and in the fourth through a ſpace 1. After compleating which, by reaſon of gravity, it falls back again, and thus in the firſt moment through 1, in the ſecond through 3, in the third through 5, and in the fourth through 7. In which laſt moment it has by the fall acquired the ſame force again, with which in the firſt it began to aſcend.

§. 43. A weight faſtened at a thread A C fig. 6. plate 1. moveable about a fixed point C, is called a pendulum; and thread and weight together are called a plummet.

§. 44. So long as the pendulum hangs in the perpendicular line C A, it is at reſt; as in no other line but this it can fall, §. 17. and is ſuſtained by the fixed point C. So ſoon therefore as the weight with the extended thread is raiſed, it comes out of the ſtate of reſt, and endeavours to fall in another perpendicular line B D. But as it is withheld here from falling by the thread, and thus drawn towards C by the re-action of the thread B C; it falls down to A by a compound motion, §. 13. The line B A, through which it takes its way between B C and B D, is an arch of a circle; as the line B C, in which it is drawn to C, is conſtantly of a length, and conſequently the ball itſelf always retains one and the ſame diſtance from C. This deſcent is equivalent to the fall through the height BD or EA. And ſo it acquires a force, with which it can again aſcend an equal height, §. 42. In the perpendicular EA this cannot happen, as the weight has acquired an impulſe in the right line AF, which forms a right angle with the perpendicular EA. And thus by the compound motion it aſcends in the curve line AG to the point G, as high above F, as E is above A, or B above D. And now its acquired velocity is ſpent. And ſo by its gravity it returns back, and again aſcends to B. Theſe motions of aſcent and deſcent from B to G, and G to B are called *vibrations*, *oſcillations*, *ſwings*. They ſhould therefore laſt without ever ceaſing. But this they do not. The arches which the pendulum deſcribes, becoming always leſs: Partly, as the thread rubs at its centre, or point of ſuſpenſion C; partly, as it moves through a reſiſting medium. The pendulum has therefore been applied to clocks, in which the wheel-work reſtores again the motion, which it is deprived of by the external reſiſtance.

§. 45. In the velocity of the pendulum we are to conſider the length of the thread, and the gravity of the weight. If therefore two weights, one of which is heavier than the other, hang at equally long threads, and fall from equal heights; the heavier vibrates quicker than the lighter, §. 9, 37.

§. 46. If therefore a pendulum is conveyed to ſome other part, but remaining unaltered in length, and vibrating ſlower in this laſt place; we may thence learn, that its gravity has undergone a decreaſe: But vibrating quicker in that other place, that its gravity is increaſed.

§. 47. If therefore two pendulums are equally heavy, and one moves ſlower, and the other quicker; the firſt is longer than the ſecond.

§. 48. If a heavy body is thrown either in an oblique, or in an horizontal line A C fig. 7, 8. plate I. it deſcribes a parabolic line. Were it without gravity, by the ſingle force of the throw, in the firſt moment it would come from A to I; in the ſecond, from I to II; and in the third, from II to III; and all theſe lines deſcribed in equal times, would be mutually equal, §. 10. Whereas by the gravity the projected body is forced to take a line *acde* perpendicular to the centre of the earth: So that its motion is compounded. And thus in the firſt moment it deſcribes the line between both the lines A I and A c, and in one and that the firſt moment comes to 1; in two moments between A II and A d to 4, and in three moments between A III and A e to 9. And as the lines I 1, II 4, and

III 9, are equal and parallel to the lines A c, A d, A e; ſo A c is to A d, as 1 to 4; and A c to A e as 1 to 9. And further as the lines A I, A II, A III are equal to the lines c 1, d 4, e 9; ſo the ſquare of the line c 1, is to the ſquare of the line d 4, as 1 to 4; and the ſquare of the line c 1 to the ſquare of the line e 9, as 1 to 9. And therefore A c is to A d, as the ſquare of the line c 1 to the ſquare of the line d 4; and A c to A e, as the ſquare of the line c 1 to the ſquare of the line e 9. The lines A c, A d, A e, are called *abſciſſæ*, and the lines c 1, d 4, e 9, *ſemiordinates.* And thus the abſciſſæ are to each other, as the ſquares of the ſemiordinates. The line drawn through the extremities 1, 4, 9 of thoſe ſemiordinates, is called a parabolick line. The thing may be ſhewn by the parabolical machine, where A I, A II, A III, exhibit the times, and I 1, II 4, III 9, the ſquares of the times, as the ſquares of the fall, §. 34. as *Graveſande* deſcribes this in his *Elementa Phyſices*, T. I. c. 24.

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The DOCTRINE of the FORCES, with which BODIES mutually act on each other.

CHAP. I.

Of the DIVISION of BODIES according to theſe FORCES.

§. 49. A BODY is called *fluid*, if its parts are ſeparable from each other by a ſmall motion of a body moving between them, as of a finger; hereby acquiring a motion among themſelves, whereby they ſeek to expand themſelves in all directions, and again fill up the former ſpace, on the cauſe of the ſeparation ceaſing. But if the connection or coheſion of the parts be ſtronger, the body is called *firm* or *ſolid.*

§. 50. The cohering parts of a body, whether fluid or ſolid, may have ſmall ſpaces or interſtices between them, in which there is no corpuſcle of the ſame kind. Such a body is called porous or rare. The poroſity may be greater or leſs according to the quantity and number of the intermediate ſmall ſpaces. The leſs in compariſon of a greater, is called *denſity.*

§.

§. 51. If the poroſity is of ſuch a nature, as that the cohering parts may be brought into a ſmaller ſpace by a determinate force, the body is called *ſoft*. But if the parts admit not to be thus brought into a narrower ſpace, the body is called *hard*. If the parts of a ſoft body have the force of expanding themſelves into a greater ſpace, ſo ſoon as the power of the compreſſion ceaſes; ſuch a body is called *elaſtick*, as a ſpring for inſtance.

CHAP. II.

Of the Forces with which Bodies hang together or cohere.

§. 52. WITHOUT contact no body can cohere with another. The degree of ſtrength, or the intenſeneſs of the coheſion is to be ſought for, partly in the forces, with which the ſingle parts of bodies act on each other; partly in the number of the points of contact. A particular account of coheſion *M. Hamberger* has given in his Phyſicks, c. 3.

§. 53. The ſmoother therefore the ſurfaces of ſolid bodies, and the more the inviſible cavities in the ſurfaces, by which they mutually touch, are filled with a matter, that fits therein; the ſtronger will their coheſion prove, ſo the forces of coheſion, with which the bodies act on each other, are not weakened by an oppoſite force. This appears from the memorable experiment made by *Muſchenbroeck*, and deſcribed in his phyſicks, c. 20. Take, for inſtance, two ſolid cylinders of lead, each of which has an ear at the baſe, through which a ſtring is drawn. The diameter of the baſes may amount to about two lines. With a ſharp knife ſhave the baſes of both cylinders ſmooth, and then preſs them with a twiſt or turn on each other. And they directly cohere. Hang the one cylinder with its ſtring at a faſtened nail. At the ſtring of the under cylinder hang on one pound after another: Which may be increaſed to twenty pounds and upwards, before the under cylinder parts from the upper.

M. Muſchenbroeck having heated two braſs cylinders, whoſe baſes were poliſhed, and in diameter $1\frac{11}{12}$ *Rhinland* inch, dipt their ſurfaces in melted pitch, and then ſet them on each other and ſuffered them to cool. Each cylinder had an iron hook, through which paſſed a copper ring $\frac{3}{10}$ of an inch in thickneſs. The one cylinder he hung at its ring by a rope, and at the ring of the under a weight of 1400 pounds; and rings and hooks flew to pieces, without the cylinders parting. See his *Introductio ad cohærentiam firmorum*, c. 1. §. 5.

§. 54. If a fluid touches a ſolid body of a denſer ſpecies, the parts of the fluid riſe up at the ſolid. For as the ſolid body is denſer, its ſurface may touch in more points than the ſurface of the fluid. And therefore the parts of the fluid and ſolid act ſtonger on each other, than the parts of the fluid on each other. But if the ſolid body is of a more porous kind than the fluid, the action of the parts of the fluid on each other is ſtronger than the action between the parts of the fluid and ſolid. So that the fluid cannot ſo ſtrongly cohere with the ſolid as the parts of the fluid unite with each other, §. 52. The experiments to this purpoſe are fully explained by *M. Muſchenbroeck* in his *Diſſertatio de tubis capillaribus vitreis & de attractione ſpeculorum planorum vitreorum.* Glaſs tubes in diameter leſs than $\frac{1}{10}$ of an inch, and called capillary tubes, open at top and bottom, afford examples to this purpoſe. If ſuch a capillary tube is with the one end dipt in water, the water riſes higher within it than it ſtands without. But if dipt in quickſilver, the quickſilver ſtands deeper internally in the tube, than externally.

§. 55. If a drop of water runs down on a glaſs, which you incline in decanting; the reaſon of its taking this way, is its being impelled by two conſpiring forces; the one the force of gravity; the other, the force with which the water acts on the glaſs, §. 13.

§. 56. If the parts of a hard body cohere equally ſtrong, and ſtand ſo connected, as that the one being extended or ſtretched, many others are extended equally ſtrong; the body breaks in many pieces, ſo ſoon as one part is by the extenſion ſeparated from the other. For, the other parts being ſtretched equally ſtrong, as they cohere no ſtronger together than the firſt, which is broke off, will therefore at the ſame time be brought out of their coheſion. Peculiar examples of ſuch brittle bodies glaſs-drops, or *lacrymæ vitreæ*, and ſpringing cucurbits offer'd. A glaſs-drop is produced, on letting fall a drop of melted glaſs into cold water; and in falling in there draws or trails, beſides, a thread from the reſt of the glaſs, ere it parts therefrom. The moment the drop falls into the water, it turns to a ſolid body, before ever the thread comes into it. And hereby it comes to conſiſt of an oblong thick part and of a thread; the former of which is called the head; the latter, the tail. On holding the head firm between the thumb and fore-finger, and breaking off a little of the tail, the entire drop ſprings or flies at once to ſmall particles like a duſt. This happens in the following manner. Such a glaſs-drop is to be conſidered as a body conſiſting of threads only, which run together the length of the head and tail to a point, and apply very cloſe to each other, and therefore are very hard and greatly ſtretched, on the melted drop falling into the water. Now on breaking off a little bit of the tail, all the threads are ſtretched throughout equally ſtrong. And thus a bit breaking, they all ſpring or fly to pieces as all the parts are equally brittle. In this manner Baron *Wolfius* explains this flying of the drop in his *uſeful Experiments*, P. 3. c. 3. The ſpringing cucurbits are ſo called from their figure, reſembling a glaſs cucurbit or body, uſed for diſtilling or abſtracting by apothecaries; and their bottom directly flies on letting a ſmall pointed particle of a flint fall internally on it; tho' its bottom is ſo firmly arched, that you may ſtrike it externally againſt a wall, and not make it fly. Profeſſor *Hanow* at *Dantzick* has made extraordinary experiments therewith, deſcribed in the firſt part of the experiments of the philoſophical ſociety in *Dantzick*. Theſe ſpringing bodies are alſo called *Bolognian flaſks*, as being made known anew, after Mr. *Boyle*, by *Amadei* a canon of *Bologna*. They are not cooled in the cooling furnace, and therefore are brittle and very ſtrongly ſtretched in every part, as coming directly out of the greateſt glow into the cold air.

Sometimes they ſpring or fly in pieces by the bare warmth of the hand. From this it appears, that the particles of glaſs are ſo ſtrongly ſtrung as to tear in pieces, when their extenſion or ſtretch is increaſed only by a ſmall force. The brittle particles continue going on to the internal bottom of a ſpringing body, and at laſt run to a point. And thus if only a thin ſhiver be tore on the upper ſurface of the internal bottom by the fall of a ſmall pointed peble, the crack propagates itſelf all over the bottom. It will be aſked, why the bottom does not fly, when ſtruck externally either againſt a wall, or on letting fall a pointed peble on its external rounding or bulge? The middle on the outer rounding of an arch is ſupported quite around by all its parts. *M. Bianconi* in a letter to *M. Scipio Maffei*, has made uncommon reflections on the nature of theſe ſpringing bodies.

§. 57. The coheſion of bodies is divided into the unconditional or abſolute, which withſtands the force, that tends to tear a body lengthways; and into the conditional or relative, which withſtands the force, that has a tendency to break a body in the direction of a line, drawn perpendicular to its length. Both kinds of coheſion *M. Muſchenbroeck* has enquired into with great care, and exhibited the experiments he made, and the propoſitions he thereby diſcovered in his *Introductio ad cohærentiam corporum firmorum.* In examining the firmneſs and abſolute coheſion of metals, he cauſed to make four threads or wires of each metal, the thickeſt of which was $\frac{1}{10}$ of a *Rhinland* inch * in diameter. As the metal in drawing was become ſomewhat ſhort or brittle, he again ſoftened the wires in a clear coal fire, whereby he freed them of their brittleneſs. In order accurately to diſcover the firmneſs of theſe wires by hanging on weights, he applied a peculiar apparatus for the purpoſe, which he deſcribes c. 3. and exhibits plate 20. increaſing gradually the appended weights. And hereby the wires by little and little became longer and ſlenderer. The experiments made with the wires $\frac{1}{10}$ of an inch in thickneſs exhibit what follows: A wire of piſtol gold was tore aſunder by a weight of 500 *Amſterdam* pounds; a wire of ſilver not quite fine, by 370 lb. an iron wire, by 450 lb. a wire of red *Swediſh* copper, by 299 lb. a braſs wire, by 360 lb. a wire of lead by 29 lb. a wire of the fineſt tin, by 49 lb.

§. 58. If two bodies have a tendency to come together, and unite with each other; this tendency is called *attraction*, and conſidered either mathematically or phyſically. Mathematically, we with Sir *Iſ. Newton* conſider barely the quantity and intenſeneſs of the attraction. But phyſically, the queſtion turns on the cauſe and the forces, whereby ſuch a tendency ariſes. Now whether we are to look for thoſe forces in the bodies, that have a mutual conatus; or without them in a certain fluid matter, is what cannot be made out in this place.

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* Equal to $\frac{135}{1390}$ of an *Engliſh* inch. The *Rhinland* foot being to the *Engliſh* as 139 to 135.

CHAP. III.

Of the preſſure of FLUIDS.

§. 59. WHEN two bodies A and B are equally big, or of an equal bulk or equal volume, as ſuppoſe each a cubick inch; and that A weighs more than B: A is called a body of a heavier, and B of a lighter ſpecies: The former is denſer, the latter more porous. For, A weighing more than B, and having no greater bulk: It muſt needs have more maſs, §. 37. and conſequently be denſer, §. 50. If two bodies are equally big, and one weighs more than the other, the gravity peculiar to each under this equal bulk, is called the *ſpecifick.*

§. 60. If two bodies A and B, differing in ſpecifick gravity, weigh equally, the ſpecifick gravity of the one A is to that of the other B, inverſely as the bulk or volume of the ſecond B, to the bulk or volume of the firſt A: Allowing at firſt to both theſe bodies equal bulk, under which A weighs four ounces, and B one; and thus A having four times as much maſs as B, and B only the fourth part ſo much as A: B therefore in order alſo to weigh four ounces, and at the ſame time retain its degree of poroſity, muſt be four times as big as A. Now as A and B weigh equally, and the bulk of the body A is contained in that of B four times; ſo on the contrary, the ſpecifick gravity of the body B muſt be contained four times in that of A. For, the weight of each of theſe bodies ariſes from its bulk and ſpecifick gravity. Now if the bulk of A is 1, and its ſpecifick gravity 4; and the bulk of B 4, and its ſpecifick gravity 1; in both, equal wholes ariſe from equal parts.

§. 60. A fluid body, which we here conſider without elaſticity, preſſes either by its gravity downwards; or by its re-action acts either upwards or ſideways againſt an acting body, and with its preſſure acts either againſt a fluid, which is either equally or unequally heavier; or againſt a ſolid body, having either the fluid over it, or reſting on the fluid. The ſcience of theſe kinds of preſſure of fluid bodies is called *hydroſticks*; as the doctrine of the æquilibrium of bodies in general is called *ſtaticks.* A number of experiments to this purpoſe, Baron *Wolfius* has publiſhed in his *uſeful Experiments*, P. I. c. 1, 2, 3 and 8.

§. 61. The preſſure of a fluid body is a dead force. Now though it acts without motion, §. 11: Yet the ſpace is to be conſidered, which a body in connection with another would paſs over in the firſt inſtant, when by a certain preſſure brought out of its ſtate of reſt. This poſſibility of running over a certain ſpace in the firſt inſtant, is called the *velocity of the quieſcent body.* The velocity of a ſinking body, which by means of a leaver raiſes another, is to the velocity of the other aſcending body, as its diſtance from the centre of motion to the diſtance of the aſcending body from the ſame centre, §. 31. And thus we are to eſtimate the dead forces of bodies by the products of their maſſes and initial velocities; as we conſider theſe bodies as mutually connected, ſo as to begin and compleat their motion in equal times, when brought into motion.

§. 62. If in two tubes G I and H K, fig. 1. plate II. differing in width or bore, and having a communicating duct I K, whereby a fluid may paſs out of the one into the other, two fluids of a like ſpecifick gravity move in ſuch a manner, as that the one aſcends in H K, while the other ſinks down in G I, the velocity in the wider tube being to that in the narrower, inverſely as the width of the narrower H K to the width of the wider G I. For, the velocities of two bodies in equal times, are to each other as the ſpaces run over, §. 27. Suppoſe the width of the tube G I to that of the tube H K, to be as 8 to 1. And thus the fluid in G I ſinking down an inch L O, the fluid in H K aſcends eight inches. And thus the velocity of the fluid in G I is to that of the fluid in H K, as the height 1 to the height 8. But the height 1 in G I is to the height 8 in H K, inverſely as the width H K to the width G I. And thus the velocity in G I is to that in H K, inverſely as the width H K to the width G I. By the width of a tube we underſtand its internal ſpace, which is equal to its internal baſe, or to the baſe of the column of a fluid in the tube. And thus the width is a circle, when the internal ſpace of the tube is a cylinder.

§. 63. Two fluids, which in two tubes have a communicating duct, and of a like ſpecifick gravity, ſtand equally high in the tubes, be the tubes equally or unequally wide, and either both perpendicular, or the one ſtanding inclined. For, the dead forces with which theſe fluids mutually preſs, are to each other, as the products of their maſſes and initial velocities,

§. 61. If both tubes are equally wide, and ſtanding perpendicular; the maſſes and velocities of the fluids in both tubes are mutually equal. And thus too the products of the maſſes and velocities in both tubes are equal. If both the perpendicular tubes G I and H K are of different widths, fig. 1. the maſs, indeed, in G I exceeds that in H K. On the contrary, by ſo much as the maſs in G I exceeds that in H K, by ſo much inverſely the velocity in H K exceeds that in G I, §. 62. And thus the product of the maſs and velocity in G I is equal to that of the maſs and velocity in H K. If both tubes P Q and S R, fig. 2. are equally wide, but one ſtanding inclined, and the other perpendicular, the maſs in P Q is to that in S R, as the height P Q to the length S R. If, for inſtance, P Q is to S R as 1 to 2; ſo is the maſs in P Q to that in S R in like manner as 1 to 2. And therefore if the fluid in S R ſinks down an inch, that in P Q riſes two inches. And thus the velocity in S R is to that in P Q, inverſely as the maſs in P Q to that in S R. So that the product of the maſs 1 and velocity 2 in P Q is equal to the product of the maſs 2 and velocity 1 in S R. If we conſider S R as an inclined plane, the maſs in S R is the weight, and the maſs in P Q the power. Both are of equal intenſeneſs, §. 24.

§. 64. As the fluid in the narrow tube H K fig. 1. ſtands as high, as that of the ſame ſpecifick gravity in the wide tube G I, and preſſes as ſtrongly on the baſe I K, as the fluid in G I, §. 63. So we are to eſtimate the force, with which a fluid preſſes againſt the bottom of a veſſel, by the width of the bottom or baſe, and by the bare height of the tube. And ſo a pound of water in a narrow tube D C, fig. 3. plate II. preſſes as ſtrongly againſt the bottom of a veſſel A B, as a quintal of water in an equally tall tube A S F E, throughout of a width with the bottom of the narrower. This may be ſhewn by two machines, deſcribed by Baron *Wolfius* in his *Uſeful Experiments*, P. I. §. 53 and 56.

§. 65. A fluid in a veſſel may be conſidered as a number of columns, having a common baſe, and being of the ſame ſpecifick gravity. So that they preſs equally ſtrong againſt each other. And thus one muſt be as high as the other, or their upper ſurfaces muſt all of them be equidiſtant from the horizontal line or level. This ſtate of a fluid is called its *level*. If the fluid matter either at the ſides, or in the middle of the veſſel be raiſed above the level, this is owing either to its acting ſtronger at the ſides againſt the matter of the veſſel, or in the middle againſt its own parts, than the preſſure ariſing from gravity, §. 54.

§. 66. If two fluids of unequal ſpecifick gravity preſs againſt each other in two tubes having a common baſe, their heights are in the inverſe ratio of their ſpecifick gravities. For, thus they weigh equal. As for inſtance, the ſpecifick gravity of water is to that of quickſilver, as 1 to 14. Now if the quickſilver ſtands in its tube one inch high, the water in its tube has a height of fourteen inches. And thus the height of the water is to that of the quickſilver, inverſely as the ſpecifick gravity of the quickſilver to that of the water. The reaſon thereof may be thus diſcovered. If the tubes are equally wide, a cylinder of quickſilver, one inch high, weighs as much as a cylinder of water fourteen inches high, §. 59. And thus neither the water can be forced up higher by the quickſilver, nor this by that: So that in both tubes there are equal maſſes, §. 37. The initial velocities are alſo equal, as the tubes are of a width. And thus the quickſilver and water hereby act with equally ſtrong forces againſt each other. So that their heights are in the inverſe ratio of their ſpecifick gravities, §. 61. Alſo they act with equal intenſeneſs againſt each other, though one tube be wider than the other. The tube, in which, for inſtance, the quickſilver ſtands one inch high, may be eight times as wide as the other, in which the water ſtands fourteen inches high. The one inch high column of quickſilver has therefore eight times as much maſs, as the water-column of fourteen inches high. So that it appears, as if the water-column could not maintain its height of fourteen inches againſt the preſſure of the quickſilver. But did the quickſilver in an inſtant ſink down a line in its tube, the water in the ſame inſtant muſt riſe eight lines in its tube. And thus the initial velocity of the quickſilver in its tube would be to that of the water in its tube, as 1 to 8, §. 27. What therefore the water wants in maſs, is compenſated by the velocity: And what the quickſilver has in maſs above the water, it loſes in velocity.

§. 67. A fluid in which a ſolid is to plunge, may be at reſt, and have ſo ſmall a coheſion of its parts, as that in regard to the gravity of the ſolid, it may be conſidered as nothing. Now if ſuch a fluid is of the lighter ſpecies, and the ſolid plunged or immerſed therein, of the heavier, it quite plunges in, when left to its weight; but loſes ſo much thereof, as a part of the fluid, equal thereto weighs. For, being of a heavier ſpecies than the fluid; a part thereof, in bulk equal to that of the ſolid, weighs leſs than the ſolid, §. 59. and thus by its re-action cannot reſtrain the ſolid in the act of plunging, §. 7. But ſo much as the part weighs, which the ſolid within the fluid drives out of its place, ſo ſtrongly it acts on the plunging body, and thus cauſes a counterpoize to the ſolid, unable to ſink. If, for inſtance, you hang at each arm of a balance a cubic inch of lead in *Rhinland* meaſure, they weigh equally, and the tongue of the balance ſtands exactly in the middle. But if the cubic inch A be ſunk in ſpring-water, the cubic inch B at the other arm gives a bias. Baron *Wolfius* in his *Uſeful Experiments*, P. I. §. 7. relates, he found a cubic inch of ſpring-water to weigh four hundred ninety-five grains. So many grains therefore as a cubic inch of lead in *Rhinland* meaſure loſes in ſpring-water; ſo many muſt be added thereto, to make it weigh again as much as the other.

A piece of lead of two cubic inches loſes therefore twice four hundred ninety-five grains, when plunged or immerſed in this water: For, it removes two cubic inches of water. Call this piece of lead B, and call another piece of a cubic inch A. And what A loſes in weight in ſpring water is to what B loſes in the ſame water as 1 to 2. Now ſuppoſing both pieces of the unequally weighing bodies A and B to be homogeneous, and plunged in a homogeneous fluid of a lighter ſpecies; what the one A loſes in weight therein, is to what the other B loſes in the ſame, as the weight of the body A to the weight of the body B. Suppoſe A and B to be lead, and A to weigh thirty-ſeven pounds, and B three hundred ſeventy pounds. A loſes in the water five pounds, and therefore B fifty pounds. For, 37 : 370 : : 5 : 50. And wanting to know the weight of B, and at the ſame time knowing it loſt fifty pounds; you will in like manner find, that the weight was three hundred ſeventy pounds. For, 5 : 50 : : 37 : 370.

§. 68. And thus the ſpecifick gravity of a fluid A is to the ſpecifick gravity of a ſolid B of a heavier ſpecies, as what B loſt in weight in the fluid, is to its entire weight. For inſtance, lead loſes in water ſomething more than the 11th part of its weight. And thus the gravity of water is to that of lead, as 1 to 11: as a cubic inch of lead weighs eleven times as much, as a cubic inch of water.

§. 69. As a denſer matter is of a heavier ſpecies than a rarer, §. 59. So a body of a heavier ſpecies loſes in a denſer fluid, more of its weight than in a rarer fluid. A cubic inch of lead in *Rhinland* meaſure loſes in ſpirits of wine leſs than four hundred ninety-five grains.

§. 70. As therefore what a body loſes in weight in one fluid A, is to what it loſes in another fluid B; ſo is the denſity and gravity of the fluid A to the denſity and gravity of the fluid B. And thus the gravity of ſpring-water is to the gravity of ſpirit of wine, as 640 to 544, as Baron *Wolfius* ſhews in the quoted place, §. 184. The inſtruments which theſe enquiries are made with, are called *areometers*, to which belong hydrometers and ſalt-gages, of which *Wolfius* treats in the cited book, §. 207—211, and *Leupold* in his *Theatrum ſtaticum univerſale*, P. II. c. 6.

§. 71. If two equally weiging bodies A and B; of which A is of a heavier ſpecies than B, are plunged in one and the ſame fluid; A loſes leſs of its weight than B. For, though A is equal to B in weight, yet in bulk it is leſs than B. And ſo a leſs quantity of fluid reſiſts the body A, §. 67.

What a body A of a heavier ſpecies loſes in a fluid, is to what a body B of a lighter ſpecies loſes in the ſame fluid, when both are of equal weight, as the bulk or volume of the body A to that of the body B, §. 67. As if A has 1, and B 4 cubic inches in bulk, ſo A in ſinking removes 1, and B four cubic inches of water. And thus what A loſes would be to what B loſes, as 1 to 4.

As the ratio of the volumes is inſeparable from the ratio of the weights loſt by equally weighing bodies, which differ in ſpecific gravity; ſo the preceeding propoſition may be converted. Namely, the bulk or volume of a body, as B is to that of a body, as A, when both are of equal weight, as what B loſt in weight in a fluid, to what A loſt in the ſame fluid.

But now in bodies of equal weight A and B, the ſpecific gravity of the body A is to that of the body B, inverſely as the bulk or volume of B to that of A, §. 59. So that in bodies of equal weight the ſpecific gravity of the one A is to that of the other B, inverſely as what B loſes in weight, is to what A loſes in weight. And thus by plunging or immerſing ſolids in one and the ſame fluid the ratio of their ſpecific gravities may be found.

§. 72. And thus if a body given out for an unmixed or unalloyed metal, loſes in water either more or leſs of its weight, than a piece of equal weight of pure metal, given out as ſuch; in the firſt caſe it is alloyed with a metal of a lighter, and in the ſecond, with one of a heavier ſpecies: And knowing the ſpecies of the alloying metal, you may find how much thereof is contained in the given body, on obſerving the rules, by which *Archimedes* diſcovered the quantity of ſilver uſed in the crown; for making which king *Hiero* or *Gelo* of *Syracuſe* gave a goldſmith pure fine gold. *Vitruvius* relates the ſtory, lib. 9. c. 3. of his Architecture. *Archimedes* took a piece of pure gold, and a piece of pure ſilver, weighing each as much as the crown. Theſe three bodies of equal weight he plunged in water, obſerving what weight each loſt in the water. The weight loſt by the piece of gold he deducted as well from the weight loſt by the piece of ſilver, as from that loſt by the crown. The overplus of the weight loſt by the crown over the weight loſt by the piece of gold he multiplied by the weight of the crown; and the product thence ariſing he divided by the overplus of the weight loſt by the piece of ſilver over the weight loſt by a piece of gold of equal weight. The quotient thence ariſing ſhewed the weight of the ſilver, mixed with the gold in the crown. We will ſuppoſe, the goldſmith received eighteen pounds of pure gold, reckoning the pound at thirty-two loths or half ounces, and that he made a crown 18 lb. in weight. A piece of pure gold of 18 lb. loſes in water 32 loths, and a piece of pure ſilver of 18 lb. loſes in the ſame fifty loths of its weight. We will ſuppoſe the crown loſt in the water 44 loths of its weight. And deducting 32 from 50, the overplus of what the piece of ſilver of 18 lb. loſt in weight over what the piece of gold of 18 lb. loſt of its weight, is 18 loths. And deducting 32 from 44, the overplus of weight loſt by the crown of 18 lb. over the weight loſt by the piece of gold of 18 lb. is 12 loths. And thus multiplying 12 loths by 18 lb. or 576 loths, the product is 6912 loths: And dividing this product by 18 loths, the quotient is 384 loths, and conſequently 12 lb: So much ſilver therefore was mixed with the crown. As the overplus, 18 loths, ariſes from 18 lb. of ſilver; ſo the overplus, 12 loths, ariſes from 12 lb. of ſilver. The overplus 18 loths, is an effect of the 18 lb. of ſilver, as a whole; and the overplus, 12 loths, an effect of the 12 lb. of ſilver, as of a part of the whole. Now as a whole A of the ſame ſpecies is to one of its parts B; ſo alſo is the effect of the whole A to the effect of this its part B. Or, there is one and the ſame ratio between the whole and a determinate part thereof, and between the effect of the whole, and the effect of its determinate part. Thus,

l. l. lb. lb.
18 : 12 :: 18 : 12.

The general rule by which we may find the quantity a body, mixed up of two ſorts of known metals, contains of each of both metals, conſiſts thus in the following particulars. Seek the quantity of weight, which as well a piece of metal of the lighter ſpecies, of equal weight with the alloyed body, as alſo a piece of the heavier ſpecies, of equal weight with the ſame alloyed body, and that which the alloyed body itſelf loſes in water. Seek the overplus, by which the weight loſt by the piece of metal of the lighter ſpecies, exceeds the weight loſt by a piece of metal of equal weight, of the heavier ſpecies; as alſo the overplus, by which the weight loſt by the alloyed body exceeds the weight loſt by the piece of metal of the heavier ſpecies. Multiply this ſecond overplus by the whole weight of the alloyed body, and divide the product thence ariſing, by the firſt overplus. And the quotient ſhews the quantity of metal of the lighter ſpecies, that was mixed among the metal of the heavier ſpecies in the given body. The demonſtration of this rule Baron *Wolfius* gives analytically in his *Elementa Hydroſtaticæ*, §. 81.

It is not even neceſſary to plunge in water a piece, equal in weight with the body, of the two metals mixed together therein. As you may take a piece of each, that weighs leſs than the mixed body, and by the rule of three ſeek how much this metal would loſe of its weight in water, were its weight equal to that of the mixed body. For, the leſs piece, and the greater, which weighs as much as the mixed body, are two unequally heavy bodies A and B, conſiſting of one and the ſame matter. If two ſuch bodies are plunged in one and the ſame fluid, which is of a lighter ſpecies than they are; the weight loſt by the body A is to that loſt by the body B, as the weight of the body A to that of the body B, §. 67. And thus knowing the weight of A, and what it loſt in water, and the weight of B, we may find by the rule of three the weight which B muſt loſe in water: As 37 lb. of tin loſing 5 lb. in water, 120 lb. loſe therein $16\frac{8}{37}$ lb. For, $37 : 120 : : 5 : 16\frac{8}{37}$.

If a piece of metal mixed up of two metals has a ſmall weight, as a ſilver coin alloyed with copper: In order to find the quantity of each metal contained in the entire piece, we require a hydroſtatical balance, ſuch as that invented by *M. Leutman* of *Peterſburgh*, and therefore called the *Peterſburgh* balance, and deſcribed in the *Commentarii Academiæ Petropolitanæ*, T. II. p. 64. It conſiſts of a long and a ſhort arm. The ſhorter is to the longer as 1 to 8. But the weight in the ſcale of the ſhorter arm is to that in the ſcale of the longer, as 8 to 1. And thus the balance ſtands with its beam level. So that if the ſcale of the ſhorter arm has eight drams, the ſcale of the longer need have only one, for the balance-beam to ſtand level. The weight with which a body is weighed at this balance, is thus eight times greater than the body. Its advantage is this: Were, for inſtance, a dram, eight of which make an ounce, or two loths, divided into a hundred parts, inſtead of the dram you divide an ounce into an hundred parts. And ſo a hundredth part of an ounce effects even what a hundredth part of a dram does.

Now as a hundredth part of an ounce is ſenſible, ſo a hundredth part of a dram may be diſtinguiſhed thereby, which would otherwiſe remain undiſtinguiſhable and inſenſible. What advantage this balance is of in examining metals hydroſtatically, *M. Leutman* ſhews in the *Commentarii Academiæ Petropolitanæ*, T. III. p. 138, &c. Two pieces of metal mixed up, for inſtance, of ſilver and copper, may have one and the ſame weight, tho' the one have more copper than the other; and the difference of the weight, which they loſe in water, may notwithſtanding be unobſervable. As fifteen loths of ſilver mixed up with one loth of copper, make 288 grains, 18 of which are reckoned to a loth: And fourteen loths of ſilver, mixed up with two loths of copper, alſo make 288 grains. Now on knowing how much a piece of ſilver of 100 lb. and a piece of copper of an equal weight loſe in water of their weight, and conſequently weigh therein, and reckoning by *Archimedes*'s rules; in the examples adduced, the 288 grains of the firſt mixture muſt weigh in water 260 $\frac{50}{554}$; and the 288 grains of the ſecond, 259 $\frac{1621}{2216}$ grains. On a common balance the difference is not eaſily diſtinguiſhable. And leſs ſtill can it be diſtinguiſhable thereon, when the one mixture conſiſts of fifteen loths of ſilver and one loth of copper; and the other of fourteen loths, and ſeventeen grains of ſilver, and one loth and one grain of copper. The difference conſiſts in $\frac{11}{554}$ grain. For, the firſt, as was juſt mentioned, weighs in water 260 $\frac{50}{554}$; the laſt on the contrary, 260 $\frac{39}{554}$ grains. How then is it poſſible to find the difference by a common balance, between the ſilver and copper in coins of ſmall weight? But how to diſcover it by the *Peterſburgh* balance, and conſequently the addition or alloy of copper in a ſilver coin, *M. Leutman* teaches in the laſt mentioned place.

§. 73. If a ſolid is plunged in a fluid, of one and the ſame ſpecific gravity therewith; it loſes its entire weight, and plunges quite, and remains ſtanding therein, whitherſoever puſhed. For, a part of this fluid, bulk for bulk equal to the ſolid, weighs as much as the ſolid, §. 59. And thus the weight, with which the part of the fluid which it removes, acts on it, is equal to its entire weight. Then it plunges quite in. For, preſſing on a column of the fluid, §. 65. the weight of the column will be ſo much increaſed, as is the weight of the ſolid. So that the other columns muſt yield. And thus this column ſinks with the ſolid preſſing upon it. This ſinking and riſing laſt ſo long, till the column on which the ſolid preſſes, ſtands in æquilibrio with the other columns. And this muſt happen, till the plunged body ſtands equally high with all the columns of the fluid. For, having therewith one and the ſame ſpecific gravity, it is all one as an equal part of the fluid, §. 63. And therefore puſhing this ſolid into any part of the fluid, it there remains ſtanding. For, it is the very ſame thing as an equal part of the fluid, ſtand it either above, in the middle, or below in the fluid.

If a ſolid is laid on a fluid of a heavier ſpecies than itſelf, only a part thereof plunges in. For, a part of the fluid, bulk for bulk equal to the ſolid, weighs more than the ſolid, §. 59. Its weight may be to that of this part, as 1 to 2. So that the ſolid can ſink only about half. For, it can only ſink in quite, when in weight equal to the weight of a part of the fluid of equal bulk; that is in weight to that of the fluid as 1 to 1.

From this it appears, that a part of the fluid, equal in bulk to the immerſed part of the ſolid, weighs as much as the entire ſolid.

§. 74. A body ſwims or floats, which ſinks not to the bottom by its weight, to which it is reſigned in a fluid, and which in this ſtate continues to move. If plunging quite in, it ſwims or floats in it. If not quite, it floats on its ſurface. If a body retains its maſs, but comes to ſuch a ſtate, as to act therewith againſt ſo many parts of a fluid, as that the weight of the fluid is either equal to that of the body, or exceeds it; in both caſes it is capable of floating. For, in no caſe can it ſink to the bottom in this fluid.

Suppoſe a cubic inch of metal, when ſolid throughout, to fall to the bottom in water. But changed to a hollow ball or ſphere, whoſe cavity contains a greater weight of water, than itſelf weighs; it may float therein. For now the maſs of metal, which before was contained in the cubic inch, has acquired ſo much bulk, as that the weight of the portion of water, againſt which it is to act, when come into the water exceeds its weight. An inflated calf's bladder contains to the quantity of ſixteen pounds of water. And thus a body of ſixteen pounds lying in water may be made to float, on binding ſuch a bladder thereat, a inflating it in the water. A fiſh riſes and ſinks in the water; as in the firſt caſe he enlarges his air-bladder; and in the ſecond contracts it. Let a ſquirt, in which the piſton is puſhed quite home, be hung at one arm of a balance, and the under opening be ſhut, through which otherwiſe the water forces, and let the ſquirt be plunged ſo deep under water, as to cover ſtill the rod of the piſton, were the piſton quite pulled up. But while the ſquirt hangs ſo deep under the water, and the piſton ſtands internally on its bottom, let a weight, equal to the weight of the ſquirt hanging in the water, be laid on the ſcale at the other arm. While the piſton reſts on the ſquirt, the ſpace above it in the ſquirt is filled with water. Let the rod be pulled up; and the water above the piſton in the ſquirt will be forced out, and between its bottom and the piſton a ſpace void of water left. So that the ſquirt will be lighter, and the weight at the other arm of the balance give a bias. *Borellus* in his *de motu animalium*, P. I. prop. 222 ſeq. deſcribes a diving machine, in which a man by means of an inſtrument reſembling a ſquirt, may go down into the ſea, and again come up: And in prop. 224. a boat, which in like manner may be brought under water, and move therein.

§. 75. A fluid, in which a body by its weight fully immerſes, acquires ſo great an acceſſion of weight as the immerſed body loſes of its weight: For, the immerſed body removes a part in the fluid, equal bulk for bulk. This part it removes, if acting againſt it with a weight, equal to the weight of that part. And therefore it is the ſame thing, as if the fluid had acquired ſo much matter of its own ſpecies, equal to the ſpace occupied by the immerſed body.

§. 76. And thus a fluid acquires from a body of a lighter ſpecies A, that by its weight quite immerſes, a greater weight, than from a quite immerſed body B of a heavier ſpecies, when both weigh equal. For, A loſes in weight more than B, §. 71. For inſtance, a veſſel of water gains from 18 lb. of ſilver fifty loths, and from 18 lb. of gold only thirty-two loths, when both bodies are plunged quite into the water, and hung at a ſtring, §. 72.

If a body, when fully left to its weight, reſts on a fluid, the weight of the fluid will be increaſed by its whole weight. For, it acts with its entire weight againſt the fluid.

If ſuch a body is made to plunge and ſink, the weight which the fluid gains from it, may be thereby increaſed and diminiſhed. Increaſed, when the body reſting thereon, retains its bulk or volume, and by an appended weight is immerſed and ſunk. It may, for inſtance, in plunging, force a cubic inch of fluid out of its place. What this cubic inch weighs, with ſo intenſe a weight the appended body muſt act againſt the fluid. And with this weight, the weight of the fluid is thus increaſed. Diminiſhed, when the body reſting thereon, retains its weight, but its bulk is ſo leſſened, as that a part of the fluid, of equal bulk, weighs leſs than it. For, in this manner the body loſes only a part of its weight in the fluid, §. 67. And thus now leſs weight accrues to the fluid than before. For inſtance, were a cubic inch of lead changed to a hemiſphere, whoſe cavity holds a greater weight of water than the ſphere itſelf weighs; it would reſt on the water, and with its whole weight preſs thereon. Were this ſphere with its full weight changed again to the former cubic inch;

it would ſink in the water, and take from it the weight before communicated, to the quantity of weight it loſes as a cubic inch in the water. Baron *Wolfius* illuſtrates this by an experiment, which he deſcribes in his *Uſeful Experiments*, P. I. §. 194. Let a tube ſome ells long, be ſuſpended at a balance, and filled with water. In this water let a cylinder of lead be hung, faſtened with a thread at the handle, with which the tube hangs at one arm of the balance. On the ſcale at the other arm let a weight be laid equal to the weight of the tube, water and cylinder. When the tongue ſtands even, you burn off the thread with the flame of a wax-candle. So ſoon as the cylinder drops, the arm, at which the tube hangs, riſes, and the other ſinks down. But when the cylinder reaches the bottom of the tube, the balance returns to its former ſtate again. The cylinder hanging at the thread, unites its weight with the water and the tube. Which is all one as if a hollow ſphere weighing equal thereto, reſted therefore looſe on the water, barely as its cavity could hold a greater weight of water than itſelf weighed. If the thread at which the cylinder hangs is burnt; the cylinder in the fall drives every way only a part of the water in bulk equal to its own bulk. So much as this part weighs, with ſo much weight the cylinder in the fall preſſes againſt the water, and thus unites its over weight no longer with it and the tube. Which is juſt all one, as if the foregoing hollow ſphere, in weight equal to the weight of the cylinder, were changed to ſuch a cylinder, and left free to the water.

§. 77. If a body by its own weight unable to plunge quite into a fluid, is immerſed by an external force; it again riſes up when left to its own weight. For, the re-action of the fluid is ſo intenſe or ſtrong, as is the action of the external force on it, §. 8. But this action exceeds the action of the weight of the immerſed body. And thus too the reaction of the fluid exceeds the action of this weight.

The fluid loſes thus again the weight imparted to it; and if cauſed by an appended body, you eaſe it, on untying, and ſuffering the body to deſcend by its weight; as the experiment propoſed by *M. Leibnitz* ſhews, and related in the memoirs of the academy of ſciences, in the hiſtory of the cauſes of the changes of the barometer. Let a metal ball be tied at each end of a thread. The one A ſo hollow as to float in water, and at the ſame time ſuſtain the other B, which is ſolid, in the water. Both theſe balls you put into the water of the tube above deſcribed, hanging at the other arm of the balance a weight, which is equal to the weight of this tube, and of the water, and both the balls. And then you ſnip off the thread at which A and B hung, B drops down and ſinks, and the tube becomes lighter ſo long as B is deſcending.

CHAP. IV.

Of Elasticity.

§. 78. IF an unelaſtic body is thrown againſt an unyielding ſurface, it cannot recoil or move back. For the body is ſoft, and thus compreſſed in the throwing, §. 51. It is, beſides, unelaſtic, and thus has no force in itſelf to expand the compreſſed parts again to their former ſpace, §. cit. Now ſo ſtrong, as by the throw, it acts on the ſaid ſurface, ſo ſtrong this laſt re-acts on it, §. 8. So that both body and ſurface are to be conſidered as parts of a ſingle body, acting equally ſtrong on each other. Conſequently they hang together, §. 5.

If the ſurface is either raiſed above the place from which the throw is made, as the cieling; or ſtands vertical, as the wall of a room: The body thrown will part from it by its gravity. But that is no reſilition or reflection, as what muſt ariſe from another action than that of gravity.

§.

§. 79. If therefore a body reſiles from a ſolid and immoveable obſtacle at which it is thrown; this reſilition is a ſign of its elaſticity or ſpringineſs. If, for inſtance, an ivory ball is ſo held at a thread, as to preſs barely by its weight on a marble table, done all over thinly with a fat blacking; on the ſurface turned towards the table, a ſmall black circle like a point is formed. But if let fall from a height of one or two ells on the table, it directly reſiles, and ſprings upwards back from the table, and in the part of its ſurface on which it fell, is without any dent or pit; but exhibiting a much larger black circle than before, when it touched the table without falling. From this it appears, that there it was ſtrongly compreſſed, but that again by its own force it fully expanded the compreſſed parts, and thereby the reſilition aroſe. But it muſt be owned, that in the marble table at the part on which the ball had hit, a ſmall pit was made, but which is not to be obſerved, as the marble in like manner has a certain degree of elaſticity.

§. 80. The re-action of elaſticity is of the ſame degree of ſtrength, as the action whereby an elaſtic body is compreſſed; or, whereby its cohering parts are brought into another ſituation. For, the re-action of elaſticity enables the force acting in the elaſtic body, to change the ſituation of its parts in a certain degree only, ſo long as it admits of compreſſion. In order to cauſe a greater change or compreſſion, a ſtronger action is neceſſary.

§. 81. An elaſtic body admits the being compreſſed only ſo long, as its parts can be brought nearer together. Touch they either each other quite; or are there no empty ſpaces or interſtices between, into which they may be brought; it is not poſſible to bring the body into a ſmaller compaſs. Now if the preſſion, whereby an elaſtic matter which is fluid, was brought into a narrower ſpace, is diminiſhed: The query is, what is the ratio of the narrower to the wider ſpace, into which the fluid expands by its elaſticity? Above all things we are to enquire, whether this matter has in the compreſſion loſt any thing of what conſtitutes its elaſtic force; in the expanſion undergone either an increaſe or a decreaſe; or while the diminution of the particular preſſion laſted, acquired a new preſſion from any other matter. Hold none of theſe three particulars, and thus come only the preſſion and its decreaſe, and the action of elaſticity to be conſidered, when the matter expands itſelf; the narrower and ſmaller ſpace is to the wider and larger, as the ſmaller preſſion to the greater. Suppoſe, for inſtance, the fluid matter to be compreſſed in ſuch a manner into a tube equally wide throughout by a four-pound weight, as to ſtand only three inches high. If this preſſion is diminiſhed about half, as that thus only 2 lb. preſs on the elaſtic matter: this laſt ſtands now ſix inches high. As thus the ſmaller preſſion 2 is to the greater 4, ſo the ſmaller ſpace 3 to the greater 6. For, the re-action of the elaſticity is always equal to the action of the preſſing weight §. 80. If therefore the action of the preſſing weight diminiſhes; the re-action of the elaſticity will be leſs, and by its remaining action the ſpace of the elaſtic matter greater. The decreaſing action of the weight is a leſs preſſion. And thus ſo often as the leſs preſſion is contained in the greater, ſo often contains the greater ſpace under the leſs preſſion, the leſs under the greater. So often as the greater ſpace contains the leſs, ſo often is the leſs contained in the greater. As thus the leſs preſſion on the elaſtic matter is to the greater; ſo alſo is the leſs ſpace to the greater. And again, as the greater preſſion is to the leſs; ſo is the greater ſpace to the leſs. We therefore find the greater ſpace, on multiplying the greater preſſion by the leſs ſpace, and dividing the product by the leſs preſſion. The leſs ſpace we find, on multiplying the leſs preſſion by the greater ſpace, and dividing the product by the greater preſſion. As ſtand the elaſtic matter in the above tube ſix inches high, while

2 lb. preſs thereon; and you aſk, how high the matter would ſtand, if 4 lb. preſſed thereon; you find three inches height. For, the product of the leſs preſſion 2, and the greater ſpace 6, is 12, which divided by the preſſion 4, the quotient is 3.

4 : 2 : : 6 : 3.

The leſs the ſpace into which an elaſtic matter is preſſed by a greater weight, the denſer it is therein. As thus the greater preſſion, whereby an elaſtic matter is compreſſed, is to a leſs; ſo is its denſity when bearing the greater weight, to its denſity when under the leſs weight. For inſtance, if the greater preſſion is to the leſs, as 4 to 1; ſo the denſity under the greater is to that under the leſs, as 4 to 1 too. Or, if the leſs preſſion is $\frac{1}{4}$ of the greater; ſo the denſity under the leſs preſſion is alſo $\frac{1}{4}$ of the denſity under the greater. But this ratio in like manner, holds under the ſame condition, that the ratio of the ſpaces was determined by above.

§. 82. The elaſticity of an elaſtic body, compreſſed into a leſs ſpace, is to its elaſticity, when occupying a greater, inverſely as the greater to the leſs ſpace. For, the elaſticity of a compreſſed matter is always equal to the preſſion, §. 80. And thus the elaſticity of an elaſtic body, preſſed into a leſs ſpace, is to its elaſticity, when more at large, or taking up a greater ſpace, as the preſſion, whereby it is reduced to a leſs ſpace, to the preſſion, which it ſuſtains in the greater ſpace. But the greater preſſion on it in the leſs, is to the leſs preſſion in the greater ſpace, inverſely as the greater ſpace to the leſs, §. 81. For inſtance, ſuppoſe the leſs ſpace to the greater, as 1 to 2, and the preſſion, whereby an elaſtic matter is reduced to the leſs ſpace, to be to the preſſion on it in the greater, as 2 to 1: The elaſticity of the matter in the leſs ſpace 1, is to the elaſticity in the greater 2, as the greater ſpace 2 to the leſs 1.

§. 83. Stand the line HC, fig. 4. plate II. in which a body ſtrikes againſt another C, perpendicular to its ſurface ACB; or form with the line ACB, which it touches, a right angle on both ſides, that is an angle of ninety degrees; the ſtroke or ſhock is called *direct*. But form the line DC, in which a body impinges on C, an oblique angle at C with the line ACB; the ſtroke is called *oblique*. The angle DCA is denominated oblique, when its adjoining angle DCB is unequal to it. DCA is under ninety degrees, and called acute; DCB above ninety degrees, and called obtuſe. The ſtroke of a ball on another is direct, fig. 6. plate IX. when the line APM, in which the ball AB impinges on the ball *ab*, paſſes thro' the centres of both balls P and M. But happen the ſtroke in a line, that goes to one ſide of the centre of the one ball, as in the line SC, it is called oblique.

§. 84. A perfectly elaſtic body H, fig. 4. plate II. impinging directly on a body C, that neither yields nor gives, reſiles or is reflected directly back from C, and finiſhes its retrograde courſe with the very ſame celerity with which it impinged. For, the re-action of the body C happens in the perpendicular line CH, in which the action happens. So that the elaſtic body is compreſſed in the line CH, and thereby the elaſticity excited. The re-action of the body C is equal to the action of the impulſe. For the body neither yields nor gives. And thus too the elaſticity is equal to the action of the impulſe, §. 80. And thus it tends with an equal degree of ſtrength or intenſeneſs, again to expand the compreſſed body, as what it impinged with. But it can only expand in the line CH in which it impinged; as the body C neither yields nor gives. And therefore the retrograde motion or reflection muſt happen in the line of impaction, and be equal to it in velocity.

A body is called *perfectly elaſtic*, when its compreſſed parts expand in ſuch a manner, as compleatly to fill up again its former ſpace, on the entire ceaſing of the action of the cauſe of compreſſion.

§. 85. If a perfectly elaſtic ball A, fig. 5, plate II. directly impinges on one at reſt B of an equal elaſticity and maſs; A ſtands ſtill after the ſtroke, and B proceeds in the line in which it was impelled, with the very ſame celerity as A had in the ſhock. If we conſider only the maſs and celerity of an elaſtic body, we may regard it as without elaſticity. And therefore in order to examine the actions of two elaſtic bodies; we are firſt to attend to the action, ariſing from their maſſes and celerities; and then to that from their elaſticity. A and B have equal maſſes. A moves, and has a certain degree of celerity: But B is at reſt, and has none. Now in ſo far as A without elaſticity acts on B by its maſs and velocity; and B without elaſticity re-acts with equal maſs, but without velocity; the conatus of the body B to continue in its ſtate of reſt is leſs than the conatus of the body A, to force it out of its ſtate of reſt. And thus B moves in the line in which it is impelled by A §. 7. The force whereby the ſingle maſs A moved before the ſhock, moves now after the ſhock a double maſs. But the power is not increaſed: Nor is it diminiſhed. For, B re-acts barely by its maſs; and A has an equal maſs. And thus the body A loſes the half of its celerity, and B gains the other half. As A impinges on B, B will be compreſſed, as being elaſtic.

But B will be compreſſed barely by the force, which A ſtill retains for its motion. This is the force of its half velocity. With equal force B re-acts by its elaſticity, §. 80, and thus compreſſes the body A in like meaſure. And hereby A is deprived of the remaining half of its velocity. But as B loſes not the half velocity imparted to it, becauſe it is compreſſed by A; ſo B may proceed therewith. Conſequently alſo the compreſſed body A may expand again towards B. And hereby it gives the Body B a new velocity; which is the other half. For, the body was compreſſed by a force of the half velocity. And thus B gains the whole velocity with which A impinged on it.

§. 86. Impinge two balls A and B of equal elaſticity and equal maſſes, in directly oppoſite directions with unequal velocities on each other; they ſpring back from each other with interchanged velocities, fig. 5. plate II. As be the velocity with which A impinges on B, greater than the velocity with which B ſtrikes on A. As B withſtands the impinging body A; B is to be conſidered as a ball at reſt. So that it gains the velocity of the ball A. And as A withſtands the incurring body B; A is to be conſidered as a ball at reſt. So that A gains the velocity of the ball B, §. 85.

§. 87. In a row of balls at reſt, 1, 2, 3, 4, of equal elaſticity, and equal maſſes, and in contact one with another, the laſt ſprings back, when a diſtant ball C, equal to each in maſs and elaſticity, ſtrikes directly on the ball 1. C itſelf after the ſhock ſtands ſtill, fig. 6. plate II. This loſt happens therefore, becauſe it ſtrikes on the ball 1 at reſt. Hereby the ball 1 gains an equally ſtrong tendency to proceed in the line, in which it was ſtruck. But it is in contact with the ball 2 at reſt. Conſequently the ball 1 loſes its whole tendency, and the ball 2 gains a tendency to proceed, which is equal to the tendency of the ball 1. At the ball 2 lies the ball 3 at reſt. So that the ball 2 is deprived of its full tendency, and on the contrary the ball 3 gains one equal thereto. But too this tendency ceaſes inſtantly in the ball 3, as being in contact with the ball 4 at reſt. And thus the ball 4 gains the tendency, which from the impinging body C was carried to it. The ball 4 is no further in contact with any. So that inſtantly, when C impinges on the ball 1, it proceeds with that very velocity which C has in the impulſe, §. 85.

§. 88. Impinge on the firſt ball 1, and the laſt ball 4, at the ſame time two elaſtic balls C and D; both equal to each ball in the row, 1, 2, 3, 4, in elaſticity and maſs, in direct directions with unequal velocities; C ſprings back with the velocity of the ball D, and D with the velocity of C, fig. 6. plate II. For, the ball 4 gains the velocity of the impinging ball C, §. 87. Now as in the ſame time the ball D runs on the ball 4; the velocity paſſes from the ball 4 to D. So that D runs back with the velocity with which C ran on the ball 1. At the ſame time the ball 1 acquires the velocity of the impinging ball D. This velocity paſſes from the ball 1 to the impinging C. And thus C runs back with the velocity, wherewith D ran on the ball 4, §. 86.

§. 89. If a body is impelled with one and the ſame force, now in an oblique line DC, again in a perpendicular DA againſt a ſurface ACB, ſo that all the way the force remains unchanged; the oblique ſtroke which the ſurface ſuſtains in C, is leſs than the direct in A, fig. 4. plate II. For in the oblique ſtroke DC, which the ſurface undergoes in C, the body acts therein only with a part of the force, with which it is impelled in DC. Which is evident hence: The force wherewith the body is impelled in DC, is to be conſidered, as conſiſting of two conſpiring forces; one of which impells the body in the line DA; the other in the line DH; and *that* is to *this*, as the line DA to the line DH, §. 13, ſeq. The line DA ſtands perpendicular on the ſurface AC, whereas DH is parallel to the ſurface AC. As parallel lines once diſtant aſunder, never come in contact ſo long as they continue parallel; the force impelling the body in DH cannot act on the ſurface AC. So that barely the force, by which the body is impelled in DA, acts thereon. This force is only a part of the whole force, which impells the body in the oblique line DC. And thus the body in the oblique ſtroke acts only with a part of its force on the ſurface. But then if the body is impelled in the perpendicular DA with the whole force, which impels it at firſt in the oblique line DC; it acts with this whole force on the ſurface. For, as the whole force acts in DA, and DA touches the ſurface in A; ſo alſo A will be impelled by the whole force.

The angle DCA, which the oblique line DC, in which the body has its oblique direction, forms with the line CA, is called the *angle of incidence*, and the oppoſite ſide DA, its ſine. As DA forms at A with AC a right angle, the oppoſite ſide or line DC is to be conſidered as the whole ſine. DA exhibits the part of the force, from which the oblique ſtroke ariſes; and DC the whole force, which produces the direct ſtroke. And thus the oblique ſtroke in C is to the direct in A, as DA the ſine of the angle of incidence DCA, to the whole ſine DC. If, for inſtance, the angle of incidence DCA is thirty degrees; the oblique ſtroke in C is to the direct in A, as 1 to 2. For, the ſine of thirty degrees is to the whole ſine, as 5000000 to 10000000. And thus the body ſtrikes on the ſurface in C only with half the power, with which it ſtrikes on the ſurface in A.

And thus if fig. 3. plate VI. two oblique ſtrokes, as one in 𝔖O, and the other in SO, are compared together; the ſtroke in SO is to that in 𝔖O, as the ſine of the angle of incidence SOH to the ſine of the angle of incidence 𝔖OH. As ſuppoſe the angle of incidence SOH to be 17°, 41′, and the angle of incidence 𝔖OH 65°, 46′. The ſine of the firſt angle is to the line of the ſecond, as 30375, 59 to 91188, 14. And thus the oblique ſtroke in SO is to the oblique ſtroke in 𝔖O, as 1 to 3.

§. 90. If an elaſtic ball D, fig. 4. plate II. is thrown in the oblique line DC againſt a ſurface or plane ACB, that neither yields nor gives; it ſprings back in the oblique line CE on the other ſide: And the angle of incidence DCA is equal to the angle of reflection ECB. For the force, with which the ball is impelled from D to C, acts not wholly in C, conſiſting of two forces, which impel the ball at the ſame time along DA and DH. By the force DA the ſtroke happens ſo ſoon as the ball in its oblique courſe touches the plane in C. The other force DH is employed on the motion of the ball in CB, §. 89. As the line DA forms at A with AC a right angle; the ſtroke, which is made by the force, acting along it on the plane, is direct. This ſtroke happens in C, in which the ball impelled by the conſpiring forces, touches the plane; which is all one, as if impelled to C by the power in DA, along the line HC parallel to the perpendicular line DA: So that the ball by virtue of its elaſticity, tends to ſpring back from C in the perpendicular line CH, with the ſame velocity with which it advanced, §. 84. In this manner the ball, after the ſtroke, is impelled by two conſpiring forces in CH and CB. For, the force with which it was impelled in DH, it has retained entirely in the ſhock. And thus it is impelled thereby from C along CB. Now as theſe conſpiring forces, which act after the ſtroke, are equal to the conſpiring forces which acted before the ſtroke; and their lines of direction in like manner form a right angle: So the ball, after the ſhock in C, muſt continue its courſe from this point C along the diagonal CE, which with CB forms at C as great an angle, as CD does with CA at C. And here *M. de Mairan*'s thoughts on reſilition or reflection are to be conſidered with attention; the hiſtory of which

which is given in the memoires of the academy of ſciences.

If an elaſtic ball A is in contact with ſome others, as 1, 2, 3, and ſtruck on directly by a ball B, fig. 7. plate II. it acts by its ſpringineſs on all the adjoining balls at the ſame time; yet with this difference, that the ball 2, lying in a line with A and B, has the greateſt ſtroke; the others a weaker, according to the obliquity of the lines. If at the balls 1, 2, 3 rows of balls lie; in each row the laſt ball ſprings back ſo ſoon as it is ſtruck on by B.

CHAP. V.

Of the central FORCES.

§. 91. ASSUMING a point C, fig. 8. plate II. about which a body may revolve, call it, with reſpect to the curve line deſcribed about it, the *centre*. Now if a body has a conatus to approach thereto; it is called a *centripetal force*; but if a conatus to recede therefrom, a *centrifugal force*. The experiments whereby the doctrine of central forces is illuſtrated, and a machine well contrived for the purpoſe, the Abbè *Nollet* has deſcribed with uncommon diſtinctneſs in his *Leçons de Phyſique Experimentale*, T. II. Sect. 2.

Such a machine conſiſts of a vertical hanging wheel, and a table placed horizontal. In order commodiouſly to bring it into a horizontal poſition, at the foot-frame are ſcrews, by which it may be raiſed and lowered. On the table are two horizontal ſheeves or pulleys, with whirls or inciſions of different diameters, about which the ſtring goes, by means of which, the ſheeves may be turned by the wheel. The ſheeves are in the middle ſtuck on iron ſpindles. At the corners of the table are irons with round holes, and at the feet are irons with ſockets. Through the round holes of the upper irons the ſpindles are ſtuck, which with their points reſt in the ſockets of the under irons. The diſpoſition of this machine is exhibited fig. 8. plate XIII. The moveable ſheeves with the whirls or inciſions are not to be ſeen in the figure, as other larger ſheeves ſtand over them, which are faſtened on the leaf of the table, of which mention will be made below.

§. 92. If a body A fig. 8. plate II. reſting on a ſheeve or pulley, is brought out of its ſtate of reſt, and impelled towards D in the line AD; it recedes from the centre C. For, all the points after A in the line AD, are more diſtant from the centre than the point A, which is the extremity of the radius AC. The line AD, which touches the radius in A, is called the tangent of the circle. And therefore the force with which a body is impelled in the tangent, is a centrifugal force: and conſequently the force with which a body A is impelled in the radius, a centripetal force.

§. 93. If a ſheeve or ball turns round its centre; all the parts without the centre, acquire a centrifugal force. For, each ſheeve may be conſidered as divided into leſs ones, with each a peculiar periphery; and a ball too into a number of ſheeves. Suppoſe the periphery to be AFBA, fig. 8. plate II. and A to be the place of one part. The firſt ſtroke or impulſe, whereby the ſheeve or ball is to move, happens in a right line, forming with the radius AC of the ſheeve a right angle, §. 10. And thus the beginning of the motion happens in the tangent AD, §. 92.

Faſten with wax a metal ball on the rim of a horizontal ſheeve, which ſtands on a ſpindle, and may be turned round by the wheel of the machine exhibited fig. 8. plate XIII. And cut a round hole in another ſheeve, ſo as to give room to the horizontal ſheeve therein, but no where to touch the internal periphery of the ſheeve thus cut out. This ſheeve with the hole, in which is the moveable one, is ſo faſtened down as to remain immoveable on turning round the internal, and to be placed horizontal at an equal height therewith. On ſtrewing the immoveable ſheeve with ſand, and giving the moveable one ſo ſtrong a degree of motion, as that the ball muſt fly off; in the ſand on the immoveable ſheeve it deſcribes a line, which with the radius of the moveable ſheeve in the point, where the ball flies off, forms a right angle.

§. 94. By the circular motion of a ſheeve or ball therefore the centripetal force, by which its parts are connected with the centre is weakened. For, as the centrifugal force ariſing from the circular motion, acts on the centripetal; ſo the centripetal acts contrary to the centrifugal; and thus by its action, with which it ſought to draw the parts of the ſheeve or ball towards the centre, muſt employ a part againſt the centrifugal force. And this we call the weakening a force.

§. 95. The quicker therefore a body revolves round a centre, the ſtronger is its centrifugal force, and the weaker its centripetal.

§. 96. If two equally heavy bodies A and G, fig. 8. plate II. revolve in two peripheries AFBA and GHNI, *that* bigger, and *this* leſs, ſo as to finiſh their revolution in equal times with an uniform motion; the centrifugal force of the body A in the greater periphery is to that of the body G in the leſs, as the radius AC of the greater circle, to the radius GC of the leſs; that is, as the greater diſtance of the body A to the leſs of the body G from C. For, as both bodies weigh equal, and finiſh their revolutions in equal times; that is, as each returns to the point from which it ſet out in the ſame time, in which the other returns to the point from which it began its revolution; ſo the difference of the centrifugal forces ariſes from the bare difference of the celerities, §. 38. Theſe celerities are only to be eſtimated by the peripheries, which A and G run over in their revolutions; ſuppoſing the motion of each body in the periphery it paſſes over to be always uniform, or one time no quicker than another. The celerity of the body A is thus to that of the body G, as the greater periphery AFBA to the leſs GIH, §. 27. But from the geometry the greater periphery is to the leſs, as the radius AC to the radius GC; *that* being the diſtance of the body A, and *this* the diſtance of the body G from the centre C. If therefore AC is to GC, as 2 to 1, the centrifugal force of the body A is to that of the body G, as 2 to 1.

On a moveable ſheeve a wooden inſtrument, ſuch as that exhibited fig. 1. plate XIII. is ſo faſtened down by two ſcrews, that the centre C of the plane ACB comes on the centre of the ſheeve. At the ends A and B of the plane two boards A E and B D are ſet upright or perpendicular. Through theſe boards in E and D at equal heights from the plane A C B a braſs wire is drawn, which at D may be tightened. At this wire two equal balls of ivory *f* and *g* are ſtuck, readily ſliding to and fro in their holes, and tied together by a ſmall chain at braſs ears. If ſo diſtant aſunder as the length of the chain, and the one has a ſtronger impulſe than the other againſt the board next to it, that other will be drawn along by it. This inſtrument as carrying the balls at the wire, is called a *carrier*. On the plane A C B a right line is drawn at C, divided into two equal parts C A and C B, on each of which an equal number of inches is ſet off. Now if the balls at the chain, fully ſtrung, are removed equally diſtant from the centre C; as that their equators ſtand above the lines 2 and 2; and the ſheeve turned round by a ſtring and wheel; the balls remain without ſhifting above 2 and 2, be the motion never ſo quick, ſo only it cauſe no quivering in the ſheeve. Each ball by the circular motion acquires a centrifugal force. But as the diſtances of the balls from the centre C are mutually equal, and conſequently may be conſidered as two equal radii of a circle; ſo the centrifugal forces are alſo mutually equal. So intenſely therefore as the ball *f* is drawn by *g* towards D, juſt ſo intenſely is the ball *g* drawn by *f* towards E. But if the balls are ſo placed, as that the one, for inſtance, *f* lies over 3, and the other nearer the centre C, *f* flies to E and ſnatches *g* along with it. For, *f* being more diſtant from the centre C than *g*, has too a greater centrifugal force than *g*.

§. 97. If two unequally heavy bodies are equidiſtant from their centre, and move round it with equal celerities; the heavier acquires a greater centrifugal force than the lighter, §. 37. fig. 1. plate XIII. If on the wire of the carrier, inſtead of two ivory balls you ſtick braſs ones *f* and *g*, of equal ſize, but ſo hollowed, as that the weight of the ball *f* is to that of the ball *g*, as 1 to 2; and bringing theſe balls at the ſtretched chain to equal diſtances from the centre C; as that *f* ſhall lie to the left over the line 3, and *g* to the right over the line 3; and turning round the ſheeve on which the carrier is faſtened; the heavier ball *g* flies to the board D, and ſnatches the lighter along with it.

Putting into a glaſs tube ſolid and fluid matters, one of a heavier ſpecies than the other; as, for inſtance, a lead-bullet, water and oil, and leaving a ſpace which the air fills up, ſtop up then the tube; fig. 3. plate XIII. Faſten this tube on the carrier ACB in an inclining poſition. The lead bullet then occupies the undermoſt part at C, above it ſtands the water, and above that the oil, and the remaining upper ſpace the air fills up. But if you give the carrier a circular motion, this order, in which they ſtand above each other, before the carrier moves, is reverſed. The air takes the undermoſt ſpace quite to C, above it ſtands the oil, and over the oil the water, and the lead bullet riſes quite atop. Water, oil and air, have indeed, in the circular motion a greater velocity than the lead-bullet, as they are more diſtant from the centre C. But the weight of the lead-bullet exceeds that of an equal bulk of theſe fluids far more than the velocity of the lead-bullet is exceeded by the velocities of theſe matters. In like manner a part of water exceeds an equally heavy part of oil far more, than a part of water is exceeded in velocity by an equal part of oil. And this holds, on comparing oil and air according to their maſſes and velocities.

If a hollow glaſs globe with ſmall ſhot, water and oil in it, is turned round its axis, the axis ſtanding horizontal: The ſhot applies to the internal ſurface quite around in form of a broad ſtripe; the water has the form of a hollow ball, and the air fills up its internal ſpace.

§. 98. But if the maſſes of two bodies moving together round a point, are to each other in the inverſe ratio of their celerities; their centrifugal forces are mutually equal; fig. 1. plate XIII.

Place the braſs ball *f*, whoſe maſs is 1, over the line 2 to the left; and the ball *g*, whoſe maſs is 2, over 1 to the right, the chain being extended. If the ſheeve is turned round, neither moves out of its place. For, they both acquire equal centrifugal forces. And thus both ſeek to ſnatch each other along with equal intenſeneſs. For, by ſo much as the ball *f* is exceeded in weight by the ball *g*, by ſo much is *g* exceeded by *f* in celerity. So that the centrifugal forces of both balls ariſe as products from one and the ſame factors.

§. 99. If a ball ANBS, fig. 2. plate XIII. whoſe parts together have an equal centripetal force or gravity towards the centre C, while the ball is at reſt, moves round its axis NCS; the centripetal force or gravity of its parts will be moſt weakened in the equator, but ſtill leſs in the peripheries of the parallel circles, the nearer they are to the poles. This happens from two cauſes. Firſt, there ariſes in the equator a greater centrifugal force than in the peripheries of the parallel circles, ſuppoſing the bodies on the whole ſurface together to have one and the ſame maſs. For, the equator of a ball is greater than any circle thereof, running parallel with it. Now if the parallel circles perform their revolution in equal times therewith, the motion of a body in the equator is quicker, §. 27. and conſequently its centrifugal force ſtronger, than of a body in a periphery of a parallel circle, §. 95. And therefore the centripetal force, or gravity of a body in the equator, is at firſt for that reaſon more weakened, than of a body in the periphery of a parallel circle; as againſt the gravity in the equator a ſtronger centrifugal force acts than in a parallel circle. But ſecondly, the centrifugal force acts in the equator on the whole gravity, which a body has in it; and in the parallel circles only on a part of the gravity, with which a body in them has a conatus towards the centre. For, in the equator the centrifugal force acts in the line AC in direct oppoſition to the gravity, which propels a body along AC, and thus diminiſhes the actions of all parts of the gravity in AC. In a parallel circle, as *ac*, the line of direction of the gravity towards the centre is *a* C, and the line of direction of the centrifugal force is *ca*. Both lines form at *a* an oblique angle. As the gravity acts along *a* C towards the centre; it is all one, as if it conſiſted of two conſpiring forces, that acted along *ad* and *ac*, and were to each other as theſe lines, §. 13, ſeq. Now as the centrifugal force in *ca* barely acts againſt the force, with which the gravity along *ac* acts againſt it; it only diminiſhes the action of a part of the gravity. The action of its remaining part along *ad* remaining undiminiſhed. Suppoſing therefore, the centrifugal force in *ca* ſo ſtrong as in CA; yet it would leſs weaken the gravity of the body in *a*, than if this very body were in A. So that the body in *a* can loſe much leſs ſtill of its gravity by the centrifugal force, ariſing in the parallel circle *ca*, where it is leſs than that in the equator.

Take on the ſurface of a ball or ſphere two points N and S, diametrically oppoſite, or diſtant from each other on the ſurface of the ſphere one hundred and eighty degrees, and draw from N through the centre C to S a right line NCS. This line is called the *axis*, and both its extremities N and S the *poles of the ſphere.* Take on the ſurface of this ſphere two other points A and B, each of which is diſtant from a pole ninety degrees. So that from the point A, a right line ACB may again be drawn through the centre C to the point B. This is called the *diameter* of the ſphere. Deſcribe on the ſurface of the ſphere from A to B, and from B again to A a circle, by which the ſurface of the ſphere is divided into two equal parts. This circle is called the *equator of the ſphere.* The ſphere by this line is divided into two equal parts. The circle thence ariſing is a *great circle* of the ſphere, and its plane called the *plane of the equator*, and the circle itſelf oftener called the equator. Suppoſe the point *a* on the ſurface of the ſphere to be as diſtant from A, as *b* is from B; a ſegment of the ſphere between the points *a* and *b*, gives riſe to a circle, whoſe plane is parallel to that of the equator, or every way equally diſtant from it; ſuch a circle is called a parallel circle, and has a leſs diameter than the equator, and therefore is leſs than it. The points *a* and *b* in the periphery of a parallel circle are thus nearer its centre *c*, than the points of the equator A and B to its centre C. The centres of the equator and parallel circle are both to be found in the axis NCS.

§. 100. A body G, in order to deſcribe a curve line about a point C, fig. 8. plate II. muſt be impelled by two conſpiring forces; the one of which is centripetal; the other centrifugal.

Impelled only by a ſingle force, it proceeds in a right line, as GE, §. 10.

But impelled by two forces, a centripetal, and a centrifugal, but not conſpiring; and thus did the centripetal act from G to C, and the centrifugal from G to A; their lines of direction would come to be conſidered as parts of one right line. But acted thoſe two forces equally ſtrong on the body G, it would remain in its place: But acted the centripetal ſtronger than the centrifugal, it would run along the right line GC. On the contrary, acted the centrifugal ſtronger than the centripetal; it would take its way along the right line GA.

Were the body impelled by two conſpiring forces, the one of which were not centripetal; it would, indeed, in this compound motion deſcribe one diagonal after another; but from them only one right line would ariſe, §. 13. fig. 4. plate XIII. Suppoſe, for inſtance, the body impelled by the one force from D to E, and by the other from D to G, and the velocity of the firſt force to be to that of the ſecond, as the line DE to the line DG: So that the body comes along the diagonal DH to H. Suppoſe the time it takes a ſecond. In H it is impelled by the conſpiring forces to I and L. Suppoſe the velocity of the force acting from H to I to that of the other, acting from H to L, as HI to HL. And thus the body in the following ſecond goes along the diagonal HM to M. Both diagonals MH and HD form one right line. And in it the body always removes further from the point C. Suppoſe the body were in *d*, and impelled by conſpiring forces to *e* and *g*; and the velocity of the firſt to that of the ſecond, as the line *de* to the line *dg*; along the diagonal *dh* it would come to *h*. Suppoſe this to happen in a ſecond. Were it impelled in *h* by the two conſpiring forces to *i* and *l*, the velocity of the firſt of which were to that of the ſecond, as *hi* to *hl*; it would traverſe the diagonal *b*C, and in the following ſecond come to C. Both diagonals C*b* and *bd* are parts of one right line. And along it the body is carried to the point C, and thus again it deſcribes no curve line about it.

But if the one conſpiring force be conſtantly centripetal, fig. 9. plate II. whereby the body is always impelled to the point G; it deſcribes in the ſeveral parts of the time, in which it comes by means of the compound motion from A to *d*, different diagonals, which together form no right, but a curve line. The centrifugal force, which ſeeks to take off the body in a right line, muſt in that inſtant take another direction, as the centrifugal force each inſtant draws the body from the line, along which the centripetal acts, and draws or forces it towards the point G. As ſuppoſe the centrifugal force to have its firſt direction along AB, and if acting alone, might impel the body in the firſt inſtant to B; and the centripetal impel it in the firſt inſtant from A to *m*, if acting ſeparately. The velocity of the centrifugal force is thus to that of the centripetal, as AB to A*m*. And therefore the body goes along the diagonal A*b*, and in the firſt inſtant comes into the point *b*, §. 13. And now the direction of the centrifugal force is *b*D, and its velocity to that of the centripetal as *b*D to *bn*. And thus the body traverſes the diagonal *bc*, and in the ſecond inſtant reaches the point *c*. In like manner in the third inſtant it gains the point *d*. So that the body has deſcribed the curve Abcd, which it further proceeds in about G, ſo the conſpiring forces continue to act on it.

From this very reaſon, that a body deſcribes a curve, when one of the conſpiring forces is conſtantly directed to one and the ſame point, and always draws off the body towards it from the line of direction of the other force; bodies projected move in parabolic lines, as being inceſſantly impelled by the force of gravity towards the centre of the earth, §. 48.

§. 101. A compound motion may be produced as well under a right as an oblique angle of direction, by which one and the ſame diagonal line is deſcribed, fig. 4. plate XIII. As ſuppoſe the body in A to be impelled by one force towards N, and by the other at the ſame time towards Q; and the velocity of the firſt force to be to that of the ſecond, as the line AN to the line AQ. So that the body traverſes AO, and comes to O in the time in which by the ſingle action towards N it would either reach to N, or by the ſingle action towards Q, to Q. The angle of direction NAQ of thoſe conſpiring forces is oblique. Suppoſe the body at A to be impelled by conſpiring forces, whoſe lines of direction AB and AP form at A a right angle. The velocity of the force acting towards B to be to that of the other acting from A to P, as the line AB to the line AP: The body takes its way from A along the former diagonal AO; and in that line comes to O, in which by the ſingle action towards B it would either reach to B, or by the ſingle action towards P reach P. In this laſt manner, in which the lines of direction of the conſpiring forces include a right angle, the curvilinear motion is eaſieſt to be underſtood. And then the line of direction AP of the centrifugal force is a tangent, and the line of direction of the centripetal, a perpendicular.

§. 102. If a body A is impelled round a point C, towards which the centripetal force is conſtantly directed, in a curve ABD, fig. 10. plate II. the ſurfaces, or areas which it deſcribes are to each other as the times of motion. The demonſtration according to profeſſor *Kraft* in his *Prælectiones in Phyſicam Theoreticam*, §. 196, is as follows. The ſurfaces or areas, which the body deſcribes, as it moves in a curve, are triangles, into which the ſpace between the body and the centre may be divided. Suppoſe this curve to be divided in imagination into an infinite number of ſmall lines AB and BD, which may be deemed right ones. Suppoſe the body A to have a certain velocity, by which it may, in an uncommonly ſmall time T takes its way along the line Aa; but at the ſame time to be impelled by the centripetal force, which in that very time T might have carried it along the line Aα towards the centre. It therefore comes in this time T in the parallelogram AB$a\alpha$ along the diagonal AB, §. 13. And which as it finiſhes in the very time, in which by the centrifugal force alone it would have finiſhed the line Aa; but this is ſhorter than AB; ſo its velocity is ſomewhat increaſed, §. 27. With this increaſed velocity it could thus in the ſecond time T have deſcribed the line Bb equal to the line AB. But the centripetal force draws it from B to β along Bβ. So that in the parallelogram BbDβ it traverſes the diagonal BD. And thus in the ſingle time it has deſcribed the ſurface ACB; in the double, the ſurfaces ACB and BCD. But the ſurface BCD is equal to the ſurface ACB. For both the triangles ACB and BCb have equal baſes AB and Bb, and on account of the common vertex, through which a line dCe parallel to the baſe may be drawn, equal heights. But the triangle BCD is alſo equal to the triangle BCb. For, both theſe triangles are contained between one and the ſame parallel lines BC and bD, and have one and the ſame baſe BC. Now as the triangle ACB = BCb, and the triangle BCD = BCb, ſo is BCD =

ACB. And thus ACB + BCD = 2 ACB. And therefore the ſurface ACB, deſcribed in a ſingle time, is to the ſurfaces ACB and BCD, deſcribed in a double time, as the ſingle time 1 to the double time 2. This manner of concluding holds throughout the whole curve about the point C. And therefore the ſurfaces or areas, which a body by means of the central force deſcribes about a point, are equal in equal times.

§. 103. If the arches or baſes of the ſurfaces, which a body accompliſhes by the central force in equal times, are mutually equal; the curve along which the body moves, is a periphery or circumference of a circle, fig. 8. plate II. The ſurface ACE is equal to the ſurface ECL, and the arch AE, to the arch EL. If two equal triangles have equal baſes, they have alſo equal heights. In the ſaid ſurfaces the heights are the diſtances from the centre. If a line carried round a point may be divided into arches, all of them equidiſtant from the centre, it is a circular line.

As the baſes of the ſurfaces, which a body revolving in a circle deſcribes in equal times, are mutually equal; it moves on in its circular courſe, which it accompliſhes by means of the central force, at all times equally quick, or in an uniform manner.

From this it appears, that the central forces, which retain a body in the circumference of a circle, are throughout equally intenſe therein.

§. 104. But if a body moves in an ellipſis, its velocity is variable, fig. 11. plate II. An ellipſis or oval is generated as follows: Draw a right line A*a*, whoſe centre is C, and at equal diſtances therefrom mark both the points F and *f*. Take a thread F G *f*, in length equal to the line A C *a*, and by its ends faſten it down in the points F and *f*. Extend the thread with an inſtrument, with which a line may be deſcribed, and therewith deſcribe about both the points F and *f* the curve A G *a* A, which at laſt returns into itſelf. Both the points F and *f* are called the *foci*. The focus F is that to which the centripetal force of the moving body is conſtantly directed. The other *f* is conſidered as a point to which no force is directed. Through the centre C draw a right line B *b*, interſecting the line A C *a* at right angles. Both lines are called the axes of the ellipſis; A C *a* the greater or tranſverſe, and B C *b* the leſs or conjugate. The right line F G, in which the body is drawn by the centripetal force towards the focus F, is called the *radius vector*. Suppoſing the ſurfaces *a* F *c* and A F *d* to be mutually equal; if now the body is impelled by the central forces, it deſcribes them in equal times, §. 102. And therefore, the time in which it runs over the arch *ac*, is as long as the time in which it finiſhes the arch *d*A. But *ac* is leſs than *d*A. And thus it moves ſlower through *ac* than through *d*A, §. 27. The motion in the ellipſis is thus variable, or one time quicker than another.

§. 105. In *a* the body is at the greateſt diſtance from the focus F, but in A at the leaſt. And thus a body which is carried in an ellipſis by central forces, moves ſloweſt in its greateſt diſtance from the focus, and quickeſt in its leaſt: And from its greater diſtance its velocity is ſtill increaſing, the nearer it approaches in its orbit to the focus; and from its leaſt diſtance ever decreaſing, the farther the body in its orbit recedes from the focus.

On the middle of the moveable ſheeve, in the machine for the central forces, pillars are faſtened, fig. 8. plate XIII. To ſuch a pillar a radius vector is ſcrewed, which is a ſquare well poliſhed rod of iron. On this rod a braſs curſor *b* is ſtuck, which very eaſily moves to and fro on the rod. To the under part of the curſor on a ſmall round pillar ſticks a moveable braſs whirl. At this whirl is a ſmall hollow pillar, admitting into it a lead pencil. In the ſmall pillar is a ſpring, which puſhes back the pencil when preſſed upwards, and when the preſſion ceaſes. Round the pillars over the moveable ſheeve on the table of the machine move large ſheeves of wood *bde*, done over with oil-colour, and with their feet are ſcrewed on the ſurface of the table. On one of theſe ſheeves to the left a braſs pillar is ſcrewed, at which is a whirl *f* placed horizontal and eaſily moveable. The place of this pillar is to be conſidered as a focus; and the place of the other pillar *c* with its moveable whirl, juſt on the middle of the moveable ſheeve, is the other focus. Round the three whirls *b*, *c*, *f*, a ſtring goes; which is ſtretched, ſo the curſor at the radius vector is drawn out ſo far, as the ſtring drawn about the three whirls permits: And if the wheel at the machine is turned, the curſor has a centrifugal force at the radius vector, and with its lead pencil deſcribes an ellipſis on the unmoveable ſheeve.

To the pillar on the other moveable ſheeve to the right, there is alſo ſcrewed a ſquare rod of braſs *abc*. At the end *c*, where this rod is ſcrewed down, is a watch-ſpring with a thread. There is further on the rod a braſs curſor with a hollow pillar, wherein lodge a ſpring and a lead-pencil. At this curſor the thread of the watch-ſpring is faſtened. The watch-ſpring is ſo ſtout, that the curſor, which may be pulled forwards on the rod, goes back to the ſpring ſo ſoon as the curſor is let go. If now the wheel at the machine is turned, this curſor acquires a centrifugal force, and continues ever receding farther from the pillar, and by this means deſcribes a ſpiral line with its lead pencil on the ſheeve *edb*; and at length when unable to go farther, and the wheel continues moving, a circular line.

§. 106. The quantity of the central force, whereby an infinitely ſmall arch A B is deſcribed, is eſtimated by the length of the line D E, parallel to the perpendicular A C, fig. 8. plate II. The time in which the arch A E is deſcribed, you may call T. Were the body impelled by the centrifugal force alone; in the time T it would come to the point D, from which let fall, on the extremity of the arch A E, the line D E ſtanding perpendicular on A D K, or parallel with A C. So that the length of the line D E is the ſpace, along which the centrifugal force would have removed the body in the time T from the centre. And thus the length of this line D E expreſſes the quantity of the centrifugal force. But as the centripetal force conſtantly draws the body from the right line A D to the centre, §. 100; the body deſcribes the arch A E, and in the time T comes to the point E, from which the perpendicular E D is drawn on A D K. So far therefore as the centrifugal force alone would have removed the body from the centre C, ſo much the nearer has the centripetal brought it thereto. And thus in like manner may the quantity of the centripetal force be expreſſed by the length of the line DE.

As the body in the time T, in which it might be brought by the centrifugal force alone to D, approaches to the centre by means of the centripetal about the quantity of the line DE: It is all one, as if fallen from D to E by virtue of the gravity. As the time T, in which the infinitely ſmall arch AE is deſcribed, is uncommonly ſmall; ſo the central force undergoes no change in its quantity all this time. And thus the body approaches to its path in about the line DE, according to the very laws, by which heavy bodies fall through a free ſpace, where the gravity is weakened by nothing.

§. 107. As therefore both central forces, whereby a body revolves round a point, have one and the ſame meaſure; ſo they are mutually equal.

1. In a circle, the quantity of the line, by which as well the centripetal as centrifugal force is meaſured, is found on dividing the ſquare of the infinitely ſmall arch AE, which the body compleats in a certain time, by the diameter AB of the circle, fig. 8. plate II. In the parallelogram AGED the line AG is equal to the line ED. And thus AG expreſſes the quantity of the centripetal force. As the line GE is the

ſine of the arch AE, it ſtands perpendicular on the diameter AB, and is thus the mean proportional between BG and GA; as *Wolfius* ſhews in his *Elementa Geometriæ*, §. 327. So that BG : GE : : GE : GA. As the arch AE in reſpect to the entire curve is conſidered as infinitely ſmall; it differs ſo little from its ſine GE, that you may take it for the ſine. And thus BG : AE : : AE : GA. Now, 'tis true, BG is unknown, as you ſeek the line AG, and conſequently not yet known. But as GA is ſo ſmall a part of the whole diameter BA, as that BA may be taken for BG; ſo is BA : AE : : AE : GA. If therefore AE be multiplied by AE, that is, the arch AE ſquared, and this ſquare divided by the diameter BA; the quotient ſhews the quantity of the line GA, and conſequently as well of the centripetal as of the centrifugal force ED. And thus we may ſay GA, or the central force is $= \frac{AE \times AE}{BA}$ or $= \frac{AE^2}{BA}$. As ſuppoſe the diameter BA = 1000000, and the periphery = 3140000 feet; the periphery to be deſcribed in 1000 minutes, and the arch AE in one minute. And thus dividing the periphery by 1000 minutes, the arch AE which is compleated in a minute, is = 3140 feet. The ſquare of which is = 9859600, which divided by the diameter 1000000; the line AG or DE is above nine feet. And thus ſo many feet is the body brought nigher the centre C in a minute by the centripetal force, in which the centrifugal ſeeks to remove it ſo many feet from the centre.

2. The arch AE expreſſes the celerity of the body, §. 9. And thus the central force of a body moving in a circle, is the quotient ariſing on dividing the ſquare of the velocity by the diameter of the circle. Call the celerity C. And thus putting the ſquare of the celerity C^2 for the ſquare of the arch AE^2. The central force is $= \frac{C^2}{BA}$.

3. If therefore two bodies of equal maſſes move on uniformly in unequal circular peripheries ABF and GHI, fig. 8. plate II. the central force in the greater periphery is to that in the leſs, as the quotient ariſing from dividing the ſquare of the velocity in the greater circle by its diameter BA, to the quotient ariſing by dividing the ſquare of the velocity in the leſs circle by its diameter NG. The firſt quotient is $= \frac{C_2}{AB}$. Call the celerity in the leſs periphery c, and the ſecond quotient will be $= \frac{c^2}{NG}$. And therefore the central force in the greater periphery, is to that in the leſs, as $\frac{C^2}{BA}$ to $\frac{c^2}{NG}$.

§.

§. 108. From this it follows, that the central force in the greater periphery is to that in the leſs, as the quotient, on dividing the radius C A by the ſquare of the periodical time in the greater circle, to the quotient, on dividing the radius CG by the ſquare of the periodical time in the leſs circle. Call the ſquare of the periodical time in the greater circle T^2, and the ſquare of the periodical time in the leſs t^2. And thus the propoſition may be expreſſed as follows: The central force in the greater periphery is to that in the leſs as $\frac{CA}{T^2}$ to $\frac{CG}{t^2}$. The demonſtration is as follows.

The velocity in the greater periphery is to that in the leſs, as the quotient ariſing on dividing the greater periphery by its periodical time, to the quotient from dividing the leſs periphery by its periodical time. For each periphery, as a ſpace, through which the bodies run, is a product ariſing from the time and velocity, as its factors, §. 29. If therefore a periphery is divided by the time, the quotient denotes the velocity. Call the greater periphery P, and its velocity C; and the leſs p, and its velocity c: And thus $C : c :: \frac{P}{T} : \frac{p}{t}$. The peripheries of circles are to each other as their radii. Now calling the radius of the greater R, and that of the leſs r, you may ſubſtitute R and r for P and p. Conſequently $C : c :: \frac{R}{T} : \frac{r}{t}$. And thus you may take $\frac{R}{T}$ and $\frac{r}{t}$ for the celerities of the greater and leſs peripheries. Now the central forces in both peripheries are to each other, as the quotients, on dividing the ſquares of their velocities by the diameter of the circle; namely, as $\frac{C^2}{BA} : \frac{c^2}{NG}$, §. 107, n. 3. But the diameters are to each other, as the radii; that is, $BA : NG :: R : r$. And thus for $\frac{C^2}{BA} : \frac{c^2}{NG}$ you may ſubſtitute $\frac{C^2}{R} : \frac{c^2}{r}$. Now $\frac{C^2}{R} : \frac{c^2}{r} :: C^2 r : c^2 R$. For we may conſider $\frac{C^2}{R} : \frac{c^2}{r}$ as fractions. And if in each the numerator is multiplied by the denominator of the other, the products ariſing are to each other as the fractions. And thus the central force in the greater periphery is to that in the leſs, as $C^2 r : c^2 R$. As the ratio of the celereties, $C : c$, may be exchanged for the ratio of $\frac{R}{T} : \frac{r}{t}$; you may ſubſtitute for the ratio of the ſquares of the velocities, $C^2 : c^2$, the ratio of the ſquares $\frac{R^2}{T^2} : \frac{r^2}{t^2}$. And therefore for $C^2 r : c^2 R$ may be ſubſtituted $\frac{R^2 r}{T^2} : \frac{r^2 R}{t^2}$. So that the central force in the greater periphery is to that in the leſs, as $\frac{R^2 r}{T^2} : \frac{r^2 R}{t^2}$. If in theſe fractions the numerators be divided by one and the ſame quantity R*r*; the central forces are to each other, as $\frac{R}{T^2} : \frac{r}{t^2}$. Now the radius in the greater periphery is = CA, and that in the leſs = CG. So that the central force in the greater periphery is to that in the leſs, as $\frac{CA}{T^2} : \frac{CG}{t^2}$.

§. 109. If the ſquares of the periodical times, in which two bodies of equal maſſes run over their peripheries, are to each other, as the cubes of their diſtances from the centre; the central force in the greater periphery is to that in the leſs, inverſely as the ſquare of the leſs diſtance to that of the greater, fig. 8. plate II. in the greater periphery ABF, call the ſquare of the periodical time T^2, and t^2 in the leſs, and call the cube of the diſtance in the greater periphery CA^3, and the cube of the diſtance in the leſs CG^3. And this condition of the ratio of the central forces is thus expreſſed: $T^2 : t^2 :: CA^3 : CG^3$. Now the central force in the greater periphery ABF, is to that in the leſs GNI, as $\frac{CA}{T^2} : \frac{CG}{t^2}$, §. 108. As $T^2 : t^2 :: CA^3 : CG^3$; for the denominators T^2 and t^2 you may ſubſtitute the quantities CA^3 and CG^3.

CG^3. And therefore the central force in the greater periphery, is to that in the leſs, as $\frac{CA}{CA^3} : \frac{CG}{CG^3}$. And dividing the firſt fraction by CA, and the ſecond by CG; $\frac{CA}{CA^3} : \frac{CG}{CG^3} :: \frac{1}{CA^2} : \frac{1}{CG^2}$. And two fractions having the ſame numerator; the firſt is to the ſecond, as the denominator of the ſecond to the denominator of the firſt. And thus $\frac{1}{CA^2} : \frac{1}{CG^2} :: CG^2 : CA^2$. So that the central force in the greater periphery is to that in the leſs, as $CG^2 : CA^2$, or the ſquare of the diſtance from the centre in the leſs periphery to the ſquare of the diſtance in the greater.

If the bodies have unequal maſſes, the central force of the body in the greater periphery, is to the central force of the body in the leſs, as the product of the maſs of the body in the greater periphery, and the ſquare of the leſs diſtance from the centre, to the product of the maſs of the body in the leſs periphery, and the ſquare of the greater diſtance. Or ſay, the central forces of theſe bodies are to each other in the compound ratio of the direct ratio of the maſſes and inverſe ratio of the ſquares of the diſtances from the centre.

§. 110. If a body moves uniformly in the periphery of a circle; the queſtion is, what is the ratio of the centrifugal force, ariſing thereby in the body to its gravity? We are then to conſider its velocity, which if equal to what it would have on falling through a certain height, its centrifugal force is to its gravity, as the double height of the fall to the radius of the circle.

1. The velocity which a falling body acquires in the beginning of its fall through a certain height, is with us ſuch, as that with it in a time, equal to that at the end of the fall, it might run over a ſpace twice as great as the height of its fall, ſo it move uniformly, fig. 5. plate XIII. call the height of the fall CD. If the body in the inſtant it reaches the point D, gains ſuch a direction, as to be able to continue its courſe in the horizontal line DE; its motion will be no longer accelerated, but become uniform. But it is ſo quick, that the body in the time in which it has fallen through CD, deſcribes the line DE twice as great. A body may come out of a perpendicular into an horizontal direction, if, for inſtance, it runs down from A along a curve ſurface AC. For, reaching the point C, it is all one as if fallen from A to B, or from C to D, as AB is =CD. As it cannot fall perpendicular from C, it will be impelled by the force it has gained in the fall, along the horizontal

line CF, equal to DE. It proceeds not, indeed, a great way therein, as by the gravity it ſinks towards the line DE. And thus its motion is compounded, §. 13. and it deſcribes a parabolic line, and comes in the time it ſpent in the fall through AB to E, §. 48. But ſo that it finiſhes the ſpace DE, which is equal to the ſpace CF, and twice as great as CD or AB. The line CD may be fifteen *Paris* feet. So far a body falls with us in the firſt ſecond of its fall, §. 34. The line DE may be thirty feet, and therefore its velocity in D is ſo great, as therewith in the following ſecond to be able to run over thirty feet.

2. With the velocity, which the body would acquire when fallen through the height CD, it may move over the arch AE, fig. 8. plate II. The ſpace of this arch AE may be equal to the ſpace of the height CD. And thus the body finiſhes the arch AE in half the time, it would require to its fall through CD. And therefore the time ſpent along the arch AE, is to that along the height CD, as 1 to 2, or as AE to 2 CD. The time 1, or AE may be called the ſingle, and the time 2, or 2 CD the double. Now as the body in the ſingle times moves over the arch AE; the queſtion is, how far it might fall by its weight in this ſingle time? As the ſquare of the double time is to the ſquare of

the ſingle; ſo the ſpace of a falling body in the double time to its ſpace in the ſingle, §. 34. The ſpace in the double time is CD, and calling the ſtill unknown ſpace in the ſingle x, therefore.

$$4\,CD^2 : AE^2 :: CD : x.$$

The fourth proportional you find on multiplying the ſecond by the third, and dividing that product by the firſt. And thus $AE^2 \times CD \div 4\,CD^2 = x$, the ſpace in the ſingle time. If both the quantities $AE^2 \times CD$, and $4\,CD^2$ are divided by the quantity CD; there ariſe the quantities AE^2 and $4\,CD$, which are alſo to each other, as $AE^2 \times CD : 4\,CD^2$. And thus $AE^2 \div 4\,CD$ is $= x$ the ſpace, through which the body might fall in the ſingle time, in which it runs over the arch AE. This ſpace $AE^2 \div 4\,CD$ therefore denotes the quantity of the gravity of the body moving along the arch AE. Its centripetal force is $AE^2 \div BA$, §. 107. n. 1. And thus the centrifugal force of the moving body is to its gravity, as $AE^2 \div BA$ to $AE^2 \div 4\,CD$, or $\frac{AE^2}{BA}$ to $\frac{AE^2}{4\,CD}$. Theſe two quantities are to be conſidered as fractions, having the ſame numerator. And if there are two ſuch fractions, the firſt is to the ſecond, inverſely as the denominator of the ſecond to the denominator of the firſt. And thus the centrifugal force of the body is to its gravity, as 4 CD to BA. Now 4 CD is the quadruple height, and BA the entire diameter. If both wholes are halved; the centrifugal force is to the gravity, as the double height to the ſemidiameter; that is, as 2 CD to CA. As for inſtance, if the ſemidiameter of a circle be three feet, and a body moves in its periphery with the velocity, which it might acquire by the fall through fifteen feet high, its centrifugal force hereby ariſing would be to its gravity, as thirty to three, that is, as ten to one, or ten times the gravity.

3. If the height by the fall through which a body might acquire the velocity, with which it moves in the periphery of a circle, be only equal to the half radius of the circle, the centrifugal force is equal to the gravity. For thus the double height is equal to the radius. And thus the centrifugal force is to the gravity, as the radius to the radius. If, for inſtance, the height of the fall = 3, and the radius = 6 feet, the double height 6 = radius 6, fig. 4. plate XIII. If in a veſſel, which is faſtened at a vertical ſheeve DAU at U, and open towards D, and remaining ſo, there is water, or a ball; the veſſel with the ſheeve may be turned round,

without either the water or the ball falling out, ſo only the velocity of the circular motion be ſo great, as that the centrifugal force be either greater, or at leaſt as great as the gravity of the body in the veſſel, and conſequently, that it preſs againſt the bottom of the inverted veſſel either ſtronger than, or at leaſt as ſtrong as the bodies by their gravity tend to recede therefrom.

4. If therefore the centrifugal force of a body moving in the periphery of a circle be equal to its gravity; the velocity of its circular motion is equal to the velocity which it would have gained, had it fallen a height equal to the half radius.

5. And thus the time of the revolution through the entire periphery is to the time of the deſcent through the half radius, as the periphery is to the radius. For, the velocity in the periphery is equal to the velocity of the fall through the half radius, as was juſt ſhewn. But if two bodies move uniformly with one and the ſame velocity, the ſpaces which they accompliſh, are to each other as the times. If, for inſtance, a body A in ſix ſeconds runs over ſix feet, and another B with an equal velocity only one foot: B accompliſhes its ſpace in one ſecond. And thus as ſix ſeconds to one ſecond, ſo ſix feet to one foot.

The Doctrine of Fluids.

PART. I.

Of the Air.

CHAP. I.

Of the Air and Air-pump.

§. 111. THE air is that inviſible and conſtantly fluid matter, in and above our earth, which we feel on the face, on moving againſt it a flat hand at ſome diſtance, with a certain degree of quickneſs.

§. 112. The machine, by means of which the air may be taken out of veſſels or receivers, is called an air-pump. The inventor of which was *Otto Guericke*, burgomaſter in *Magdeburg*, who exhibited the firſt public experiments therewith in 1654 at *Ratiſbon*, before the emperor *Ferdinand* III, his ſon *Ferdinand* IV. king of the *Romans*, and ſeveral electors and ambaſſadors to their very great aſtoniſhment. *Guericke* himſelf deſcribed and publiſhed his diſcoveries, made with the air-pump, firſt in 1672, under the following title; *Experimenta nova Magdeburgica*; *Caſpar Schottus*, the then profeſſor of mathematicks at *Wurtzburg*, having already publiſhed them to the world in 1657, in his *Mechanica hydraulico-pneumatica*, and in 1664 in his *Technica curioſa*.

An air-pump conſiſts of a hollow tube or cylinder of metal internally poliſhed; in which, by means of a rod, a leather piſton, which fits exactly the internal ſurface of the tube, may be moved back and fore. If to the end of the tube a veſſel be ſo applied, as that between the veſſel and tube no air can inſinuate into the tube; and the piſton which reaches home to that end, be drawn towards the other end; there will be produced a ſpace void of air, or a vacuum in the tube, into which the air from the veſſel forces. But farther, the tube muſt be ſo ordered, that the air which has forced in from the veſſel into the empty ſpace, may have the communication cut off with the air ſtill in the veſſel, and be diſcharged the tube. And this may be done as well by a valve as by a cock. *Guericke* deviſed two ſorts of air-pumps, and both of them with valves. In the firſt, which has an oblique poſition, the rod, at which is the piſton, was drawn with two ropes. The other ſtood vertical, and the piſton was worked up and down by a leaver. *Schottus* deſcribes the firſt in his *Technica*, lib. i.

c. 1; and the other lib. i. c. 26. exhibiting both with their ſeveral parts and the manner of putting them together, on copper plates. Both air-pumps ſtood in water, in order to ſecure tube and veſſel againſt the ingreſs of the external air. Next, Mr. *Boyle* in *England* ſo ordered the air-pump, as to ſuperſede the uſe of water, for warding off the external air. He placed the tube vertical on a foot-frame, faſtening at the piſton an iron rod with teeth, and furniſhed with a ſtar-wheel and crank or winch; with which, in the manner of the carriers jack, the piſton might be wound or worked up and down. This air-pump he deſcribes in his *New Experiments on the Elaſticity of Air*; and *Schottus* in his *Technica*, lib. ii. This method of Mr. *Boyle* was at length changed to another, in which a ſtirrup was made to the rod of the piſton, in which a perſon might tread with one foot, in order to pull down the piſton in the vertical tube, and form an empty ſpace or vacuum. To the rod at the ſame time a handle was faſtened, with which the piſton might be puſhed up or drawn again. And at length the abbè *Nollet* carried this pump to a peculiar degree of perfection. Its principal parts he deſcribes in his *Leçons de Phyſique Experimentale*, T. III. *Leçon* X. *Experiment* I. exhibiting it as put together plate I. To this air-pump at the ſame time he applied an apparatus with a wheel, with which in vacuo a circular motion is performable. This apparatus is deſcribed *Leçon* X. *Experiment* XIII. and repreſented plate V. *Sengwerdus* a profeſſor in *Leyden*, in 1697, cauſed to make an air-pump, with a cock inſtead of a valve in its tube, and in which the piſton might be worked out and in by a wheel and croſs. The tube might be as well oblique as horizontal. Baron *Wolfius* in his *Experiments*, P. I. §. 69—79, gives a particular deſcription of it. Mr. *Hawkſbee* made air-pumps with two cylinders or barrels. The late Mr. *Leupold* of *Lipſick* had made ſuch another of his own deviſing, without having ever ſeen either *Hawkſbee*'s air-pump or a drawing of it. He deſcribes it in his ſecond continuation of the treatiſe on the air-pump. As well the cylinder or barrel, as the piſton has valves below, fig. 1, plate XIV. Both barrels A and B communicate by a horizontal tube CD, which has a cock I L. From the horizontal tube CD another tube EF goes in the intermediate ſpace between the barrels up to the horizontal plate LM of the air-pump. And thus along this tube the air forces out of the veſſel or receiver on the plate into the horizontal pipe CD, and out of this through a valve in the barrel A, in which the piſton is drawn up. And then on depreſſing this piſton, the air will be compreſſed, and thereby obliged to ſeek vent or iſſue at the valve of the piſton. And as this piſton is depreſſed, that in the other barrel B is pulled up, and in it a vacuum made, to which a part of the air, ſtill remaining in the veſſel on the plate, takes its way. The horizontal tube CD lies in a braſs box, at whoſe ends the barrels ſtand, and which is filled with water. Above the piſton there is alſo water: And hence proceeds the ſwaſhing noiſe to be heard therein, when the air is preſſed out of the barrels through the valves of the piſton into the water. The water comes to be neceſſary on account of the valves, as being of bladder. The rods of the valves are ſtuck in an iron leaver or ſwing, which in the middle is faſtened at a roller N, and may be worked by another and longer, or a double leaver HI. In the tube EF, which goes up from the horizontal tube between the barrels to the plate of the air-pump, a little below the long leaver is a round hole G, in which a poliſhed ſtopple of braſs is ſtuck; on pulling which out, air goes again into the exhauſted veſſel. The bladders, of which the valves below at the barrels conſiſt, are ſtretched over narrow openings which go into the horizontal tube. The air which forces into this tube, eſcapes in each valve on two ſides, when the piſton in the barrel is pulled up. And again on depreſſing the piſton, the bladder is preſſed cloſe to the hole by the air over it, that the air cannot go back. In the piſton likewiſe is a narrow opening, and over it a bladder ſtretched, which on two ſides is ſo cut out, that the compreſſed air under the piſton in the barrel, on being depreſſed, may force upwards at the two ſides of the bladder, but not come back. For producing the circular motion in vacuo, eſpecially in electrifying, I have cauſed to make *Nollet*'s apparatus for this air-pump. In *Graveſande*'s air-pump with two cylinders, the piſtons are with toothed rods, moveable up and down by a wheel. Profeſſor *Muſchenbroeck* has minutely deſcribed this air-pump. To this deſcription he has, beſides, added another, in which he explains and exhibits a ſingle air-pump of a peculiar ſpecies. The deſcription of both machines is to be found in his *Deſcription des nouvelles ſortes de machines pneumatiques, tant doubles que ſimples avec un recueil des pluſieurs experiences, que l'on peut faire avec ces machines*, at the end of his *Eſſai de Phyſique*. Baron *Wolfius* in his *Experiments*, Part I. §. 139. deſcribes a ſmall ſingle air-pump, a few inches only in length, having a piſton with a valve of a piece of bladder; and it may be uſed with great commodiouſneſs for diſcovering the force and effects of the air.

CHAP.

CHAP. II.

Of the Gravity and Elaſticity of the AIR.

§. 113. EACH part of the air is heavy. For, a hollow ball exhauſted of air, weighs leſs than when full of air.

§. 114. In like manner, the air is elaſtic. For, it may be compreſſed, and it is ſuſceptible of expanding again to a wider ſpace, on the ceaſing of the compreſſion. In both theſe properties elaſticity conſiſts, §. 51.

That the air has a faculty of expanding, appears even hence, that it forces into the air-pump, ſo ſoon as the piſton is drawn up. From this it is evident, that the pumping out the air properly conſiſts herein; namely, that in the air-pump a vacuum is produced, in which the air by its native force may expand itſelf. If the piſton is puſhed back again, the air is again brought out of a wider into a narrow ſpace. The elaſticity of the air appears with full evidence, on ſuſpending a firm tied bladder, containing only a little air in it under a glaſs bell, and pumping out the air. For ſo ſoon as you begin to pump, the bladder begins to heave or ſwell up a little. The more air goes out of the bell into the air-pump, the ſtronger will the bladder be blown up. But if air be re-admitted under the bell, the bladder collapſes or falls together again. As thus the ſwelling ariſes from the expanſive force of the external air; ſo its falling together, from the internal air being preſſed into a narrower ſpace by the air forcing from without under the bell. If you hang under the bell a dry and fully blown bladder, not tied quite tight; it will burſt by the expanſive force of the included air, on pumping out the external air under the bell as much as poſſible.

There is a peculiar inſtrument for compreſſing the air, by forcing in ſtill more of it into a determinate ſpace already full of air. It is called the *compreſſing machine.* It conſiſts of a braſs tube AB, fig. 2. plate XIV. with a piſton and rod, with a handle CD; by which the piſton may be pulled up, and again puſhed down. Above, at the ſide E of the tube is a ſmall hole, through which the external goes in, on pulling up the piſton above this hole. Below again in the tube at B is an opening covered with a valve. Now if the air forced in at the upper hole be driven down; this valve will be puſhed up by it, and the air expelled at the tube. Back into the tube it cannot go, as it preſſes the valve againſt the hole. This tube AB is ſcrewed to a horizontal tube BF, which is joined with a vertical tube FG, at whoſe upper end G is a ſcrew with a cock; in order to ſcrew thereon the veſſel into which you would preſs the air. Now if this ſet of tubes thus joined together, be faſtened on a wooden frame, you have a very commodious compreſſing-machine. *Sengwerdus*'s air-pump may alſo be very well employed for compreſſing. For, on winding out the piſton in the tube, and opening the cock, the air fills the whole tube. On ſhutting and turning the cock, that the air has free admiſſion into the veſſel, that is ſcrewed down on the plate of the air-pump, you may force it in, ſo you wind back the piſton.

CHAP. III.

Of the Quantity of the GRAVITY and ELASTICITY of the AIR.

§. 115. AS the air admits being compreſſed, ſo the under air is denſer than the upper. A cubic foot of air at the earth's ſurface thus weighs more, than a cubic foot on a high mountain. In like manner a cubic foot of air at the earth's ſurface is at one time heavier than at another; as the air is now charged with much, again with little vapour. Commonly its weight is eſtimated at five hundred eighty-five grains; four hundred and eighty of which make an ounce in apothecary weight, *Wolfius*'s *Experiment*, P. I. §. 86.

§. 116. The weight of a column of air from the earth's ſurface up to its limits is equal to the weight of a column of water of an equal baſe therewith, and between thirty-one and thirty-two *Rhinland* feet in height: Or, as the weight of a column of mercury, of an equal baſe with that of the column of air, and about twenty-eight inches in height. For, at the height of of between thirty-one and thirty-two feet a column of water is ſuſtained by the preſſure of the air; and at twenty-eight inches a column of mercury. *Guericke* made the experiment with water, and deſcribed the apparatus for it in his *Experim. de vacuo*, lib. iii. c. 20, 21. By the height and weight of the mercury in a glaſs tube, *Torricelli*, a profeſſor of mathematics at *Florence*, firſt diſcovered the preſſure of a column of air. And hence ſuch a tube with quickſilver was at firſt called the *Torricellian* tube; but afterward, on being applied to diſtinguiſh thereby the variation of the air's gravity, the *barometer*. On the ſea ſhore the mercury ſtands higher, than on any other part of the earth's ſurface. The greateſt height amounts in *Paris* meaſure to twenty-eight inches four lines; and the leaſt to 26″ 4‴. The variation of the heights of the mercury in the barometer happens thus within a ſpace of 24‴. If the baſe of a round column of water is a *Paris* foot in diameter, and thirty-one feet in height, its weight is 1703 $\frac{45}{100}$ pounds. And ſo great is the weight of a round column of air, whoſe baſe is a *Paris* foot in diameter. For, the ſurface or area of a circle whoſe diameter is a *Paris* foot, conſiſts of 7850 ſquare lines, each of which is a line long and a line broad. A height of thirty-one feet is 3100 lines, a foot containing 100 ſuch lines. If the ſurface 7850 is multiplied by the height 3100; the ſolid contents of this ſpace make 24335000 cubic lines; each of which is a line long, a line broad, and a line thick: 1000 cubic lines make one cubic inch. And thus the ſpace conſiſts of 24335 cubic inches. Now 1000 cubic inches of water, which make one cubic foot, weigh ſeventy pounds. And thus 1000 : 24335 : : 70 : 1703 $\frac{450}{1000}$.

Baron *Wolfius* in his *Experiments*, P. II. c. 3. and *Leupold* in his *Theatrum Staticum Univerſale*, P. II. c. 2 and 3. treat on the barometer, its conſtruction and kinds. The following experiment ſerves as a peculiar confirmation, that the quickſilver in the barometer is ſuſtained at a certain height by the preſſure of the air, fig. 3. plate XIV. At the one end of a braſs curſor BCDE a ſmall tube CB is bent upwards; and at the other end DE bent downwards; and both of them ſtand perpendicular on CD. In G is a ſcrew, well ſecured with a piece of leather well drawn or worked in tallow, that no air can pervade it. In C a glaſs tube CAB is cemented, open below where it is cemented, but ſhut above in A. In D there is another glaſs tube DEF cemented, open at both ends. On the plate of the air-pump a ſmall veſſel IH with quickſilver, and over that a glaſs KL is placed; in whoſe neck is a cork ſoaked in oil and covered with cotton. Through the middle of this cork a hole paſſes, through which the tube DF is ſtuck, and well ſecured with cotton. Then the air as much as may be, is pumped out of the glaſs KL, and both the tubes FD and CD; after which the tube DF is plunged into the quickſilver in the ſmall veſſel IH, and air left under the glaſs KL: And inſtantly the quickſilver riſes into the tube CA, as far as M, for inſtance, where is the height, at which it is wont to ſtand in the barometer. On drawing out the ſcrew G, the quickſilver in the tube DF is directly forced down by the ruſhing air into the veſſel IH, and the other quickſilver in the tube C A out of M up to A. Only the tube C A muſt not be quite too wide, that neither air nor quickſilver give way to each other. For, doing ſo, the air riſes above the quickſilver, and thus depreſſes it.

§. 117. With an equal degree of ſtrength, the air under ſuch a column of air, weigh it ever ſo little, preſſes by its ſpring againſt the weight lying on it, §. 80.

If a weight of two pounds be hung at the ſmall air-pump, of which mention was made at the end of §. 112. and the piſton pulled up, and then held faſt; the tube with the appended weight riſes up. The wider ſuch a cylinder, or hollow tube, a greater weight may be forced up by the elaſticity of the air under it. The appended weight may ſtand on a metal plate, while held on it with one hand, in the time the piſton is pulled up. And on letting go the hand, the weight with the tube riſes up. From this it plainly appears, that even the little air, which is ſtill between the weight and the plate, has a degree of elaſticity, which ſurmounts the weight preſſing upon it. If this ſmall air-pump, with the appended weight is hung under a glaſs bell; while the piſton reſts on the internal bottom of the pump; the degree of elaſticity of the air diſcovers itſelf in a twofold manner. If the air under the bell is pumped out, the tube of the pump ſinks down with the weight. But if again admitted under the bell, the tube with the weight again aſcends. By the force of the air therefore the water is forced into ſquirts, ſiphons and water-pumps, on forming a ſpace in theſe inſtruments, containing either quite none, or a very rarified air. In order to make water riſe in one leg of a ſiphon and paſs over to the other, and run out thereat, the following particulars are neceſſary. The height of the one tube reckoned from the level of the water, muſt be under thirty-one feet. And the aperture of the other, at which the water that roſe into it is to run out, muſt ſtand under the level of the water. For as the height of the tube in the water is under thirty-one feet; ſo the water by the preſſing air is forced through it into the tube. In this a ſpace void of air is produced: So that the water falls down by its weight into the outer. Now as with its mouth it ſtands under the level of the water in which the other tube dips; the weight of the column of water contained in the longer, is greater than the weight of the column of water contained in the ſhorter leg. And conſequently the weight of the water in the longer tube is greater than the counter preſſure of the air. The height in like manner, of a water-pump muſt be under thirty-one feet, as the air cannot preſs water any higher.

If ſome water-pumps ſcrewed on the plate of the air-pump, give alſo water in vacuo; this only happens, when the holes below in the plate of the rod are as narrow as capillary tubes. And thus the water riſes here by virtue of the attraction, §. 54, 58. Alſo ſome ſiphons run in vacuo: But they alſo conſiſt of very narrow tubes. And on making the experiment with ſuch a ſiphon in vacuo, both tubes become ſoon full of water. Now water, by virtue of the attraction acquires a certain degree of ropineſs, whereby a falling part of water draws and ſnatches along with it another, with which it is in contact above. And thus on opening the longer tube in vacuo, the water riſes ſo long out of the ſhorter, as the ropineſs of the water falling into the longer, is capable of drawing after it the parts of water in the ſhorter.

By the ſpring of the air, which ſtands above the water in a veſſel with a narrow aperture, it may be put in motion as well in a ſpace void, as full of air. In vacuo the water is forced up out of a veſſel; as the preſſure, which the ſpring of the air contained therein, exerts on the water, finds no reſiſtance without the veſſel. But for the water to ſpring out of a veſſel in a ſpace full of air, the ſpring of the included air muſt be heightened either by fire, or by compreſſion and condenſation. The compreſſion may be done as well by the compreſſing-machine, as alſo by water.

§. 118. As the under air is compreſſed by the upper, and tends to expand itſelf on all ſides by a force, which is equal to the preſſure of gravity, ſo it preſſes by its ſpring not only upwards, but alſo ſideways, quite as ſtrong as the weight of the entire upper air. By this weight the ſpring of the under air is excited to preſs. And from this we may explain that aſtoniſhing preſſure of the air, which *Guericke* ſhewed with two hollow hemiſpheres of copper, in diameter nearly a *Magdeburg* ell, and which could not be parted aſunder by twenty-four horſes, twelve drawing on this ſide, and twelve on that. *Schottus* exhibits this experiment in his *Technica*, lib. i. c. 15. on a copper-plate, and p. 47. adduces the letter in which *Guericke* deſcribes the experiment. A glaſs plane which is cemented on a veſſel, is cruſhed to pieces on pumping the air out of the veſſel; be the plane expoſed to the external air, either upwards, downwards, or ſideways, *Wolfius*'s *Experiments*, P. I. §. 109. So long as the air under the glaſs plane is as denſe as the air, that preſſes on it externally, the plane cannot be cruſhed by the external air: As the elaſticity of the internal acts as ſtrong, as the preſſure of the external. From a like reaſon, the hemiſpheres cannot be compreſſed by the external air, when filled with as denſe an air as the external. And this we are to conſider, when aſked how it comes, that the preſſure of the air is not incommodious to men and beaſts. For, ſuppoſing the external ſurface of a man's body to be equal to a ſpace of twenty feet ſquare, this ſurface will be preſſed on by the air as ſtrongly, as if a weight of water thirty-one feet high lay upon it. And multiplying twenty feet ſquare by thirty-one feet high, the product gives ſix hundred and twenty cubic feet. And aſſuming a cubic foot of water to weigh 70 lb. the preſſure of the air on the ſaid ſurface of a man is equal to a weight of 43400 lb. But juſt ſo ſtrongly preſſes the air contained in the ſkin and juices of the body againſt the external.

§. 119. As a cubic foot of air on the earth's ſurface weighs five hundred eighty-five grains, §. 115; ſo in cloſe veſſels uſed in making experiments, the preſſure of the air is to be eſtimated only by its elaſticity. Thus the quickſilver in the *Torricelian* tube, has in a cloſe glaſs veſſel juſt the height it has without it, when the air in the veſſel is juſt as denſe as the air without it; be the veſſel wide or narrow.

It has been ſuſpected, whether a far more ſubtle matter than air was not the cauſe, that veſſels that let no air eſcape, are ſo ſtrongly compreſſed, when including in their internal ſpace either none, or but a very rarified air. It is pretended, that the æther, or pure celeſtial air exerted the force, which we have hitherto aſcribed to the air on the earth. The following experiment ſhews how groundleſs is this conjecture, fig. 6. plate XIII. Under a glaſs bell ABC, above at D with a ſmall round hole, ſtopt up with wax, hangs another ſmaller *abc* at a ſpindle EF, which may be drawn up and again puſhed down, without any air that proves any thing conſiderable, getting by this motion under the bell. The great bell ſtands on the plate of the air-pump, the ſmaller hangs without touching the plate. After the air is fully pumped out, and thus the greater bell firmly preſſed to the plate; the hanging bell is puſhed to the plate and preſſed down upon it; ſo that its rim preſſes equally ſtrong the wet leather on the plate quite round. Now ſome are of the idle opinion, that the greater bell ABC was preſſed to the plate by the æther, as there was no air under the bell that could reſiſt its preſſure. But if the æther be the ſole cauſe, whereby the bell void of air, is preſſed to the plate, the ſmaller bell alſo *abc* muſt be faſt to the plate by the ſame cauſe, and be as little parted from it as the greater bell ABC. The experiment ſhews the contrary. On pulling at the ſpindle EF, the ſmaller bell is ſo eaſily drawn up, that no coheſion with the plate can be obſerved. If the ſmaller bell is again preſſed down on the plate of the air-pump, and a needle ſtuck in the wax of the hole D, for air to enter into the great bell over the ſmaller; the ſmaller will ſtick faſt at the plate, and the greater loſe its coheſion with it, and may thus be pulled up.

The firmneſs, with which hemiſpheres void of air, hang together or cohere, can as little be aſcribed with any ground to the alone force of the æther, fig. 7. plate XIII. A copper hemiſphere C, on which above at D an iron ring is faſtened, ſtands on a braſs plate, between four and five inches in diameter, with a cock with which the plate is ſcrewed down on the air-pump. On the plate lies a moiſt leather. The air is pumped out of the hemiſphere. You ſhut the cock below at the plate, and remove plate and hemiſphere from the air-pump, and fix on the cock an iron ring. Through this ring and the ring of the hemiſphere you draw a ſtring. On each ſide between four and five perſons may draw, without hemiſphere and plate parting aſunder. The firmneſs of the coheſion ſome would aſcribe to the bare action of the æther. But how idle is this opinion, the following experiment ſhews. Screw the plate with the hemiſphere again on the air-pump, and pump out the air quite, that in the courſe of drawing might have ſlipt through the leather into the hemiſphere. Place on the plate at the rim of the hemiſphere a trivet E F G, with a wound ſpring above, at which below is a hook. You preſs down the wound ſpring till the hook catches in the ring of the hemiſphere at *d*. And thus the ſpring by its force ſeeks to draw up the hemiſphere. But it can only draw a few pounds. So that the hemiſphere remains firm at the plate. You cover with a large glaſs bell the whole apparatus, and pump out the air. And being removed, the hemiſphere will be ſnatcht up by the ſpring. Now were the hemiſphere, previous to the pumping, preſſed to the braſs plate, not by the elaſticity of the air, but by the force of the æther; why ſhould not this æther alſo, after pumping out the air, have the power to overcome the ſmall force of the wound ſpring, and maintain in this coheſion the hemiſphere, firſt preſſed down on the braſs plate, there being air neither over nor under the hemiſphere, whoſe force can weaken the force of the æther?

§. 120. If a circular ſurface A be preſſed on by juſt ſo denſe an air as is another B; the preſſure on A to that on B, is as the ſquare of the diameter of the ſurface A to the ſquare of the diameter of the ſurface B. Suppoſe B in diameter to be one *Paris* foot; and A two; the preſſure on B is to that on A, as 1 to 4. And thus the ſurface A will be preſſed on by a force, four times as intenſe, as is the preſſure of 1703 $\frac{45}{100}$ lb. §. 116. For, if the air, preſſing on two ſurfaces, is equally denſe, the height in that caſe is then out of the queſtion. For, if both ſurfaces are preſſed on in open air, the heights of the air are in both equal. But if in cloſe veſſels; the preſſure conſiſts in the elaſtic force only, which in equally denſe air is equally intenſe, §. 119. And therefore the preſſure of equally denſe air, on two circular ſurfaces, is to be eſtimated by their magnitudes only. But the magnitudes of circular ſurfaces are to each other, as the ſquares of their diameters.

The gravity and elaſticity of the air on the earth's ſurface act therefore againſt a circular ſurface, an inch in diameter, with a preſſure, nearly equal to the preſſure of 12 lb. For, the preſſure of the air on a circular ſurface, a foot, or twelve inches in diameter, is = 1703 $\frac{45}{100}$ lb. or 54512 loths, or half ounces, nearly. The ſquare of 12 is = 144, and the ſquare of 1 = 1. Now as the ſquare 144 is to the ſquare 1; ſo is the preſſure of the air againſt a cylindrical ſurface of twelve inches in diameter, to the preſſure of the air againſt a cylindrical ſurface of one inch in diameter. And thus, 144 : 1 : :

54512 : 378, which divided by 32, the number of loths in a pound, gives eleven pounds twenty-ſix loths.

PART II.

Of FIRE.

CHAP. I.

Of the Notion of FIRE.

§. 121. FIRE is a fluid and inviſible matter, capable of expanding as well the air, as all viſible fluid, and ſolid matters on our earth. Some bodies, as moiſt wood, are, indeed, contracted by the fire. But this contraction happens not in their proper ſolid parts, but the humidity only is expelled from their interſtices.

§. 122. The expanſion produced by fire in an animal body, and perceived by the animal, is called *heat*, and the feeling or perception of its defect, *cold*. If a body contains ſo much fire, as to be able to excite *heat* in an animal body; it is called *hot*. But if of ſuch a nature, as that an animal, on contact with it may perceive cold, it is called *cold*. In propriety, a body, which excites heat, is to be called *calorifick*; and one, that produces cold, *frigorifick*. But did we diſregard the diſtinction between the cauſe and its action or effect; we muſt needs have aſcribed heat and cold to the calorific and frigorific bodies themſelves.

CHAP. II.

Of the Thermometer and Pyrometer.

§. 123. THE air, in which we live, excites at different times by means of the fire it contains, different interchanges of heat and cold in animal bodies. And this happening in animal bodies, the ſolid and fluid matters, co-exiſting with them in one and the ſame air, are now pure, again leſs expanded and contracted. The quantities of this expanſion and contraction are thus ſigns of the expanſion and contraction, which the air itſelf undergoes, by means of the ſtronger and weaker actions of the fire contained therein; and conſequently ſigns of heat and cold, which are improperly aſcribed to the air. An inſtrument, in whoſe matter a decreaſing and increaſing expanſion and contraction, produced by the heat and cold of the air, is obſervable, is called a *thermometer*, or heat-gage. Among the thermometers, in which the heat and cold of the air, and other matters, are diſtinguiſhable by the expanſion and contraction of a fluid matter, as ſpirit of wine, or quickſilver, Baron *Wolfius* in his *Experiments*, P. II. c. 5. deſcribes *Drebbel*'s, the *Florentine*, and the mercurial. A further account of the improvement of the thermometer, profeſſor *Muſchenbroeck* gives in his *Eſſai de Phyſique*, c. 26. and the abbé *Nollet* in his *Leçons de Phyſique*, P. IV. p. 393, ſeq. The quantity of heat and cold, obſervable by a thermometer, is uſually expreſſed by a certain number of degrees. We ſay, for inſtance, the heat is thirty, or the cold is twenty degrees. By this we mean to indicate, that the fluid matter in the thermometer has by the heat ſpread and expanded itſelf thirty degrees, and by the cold contracted itſelf twenty degrees. But if it be aſked, what quantities or parts are to be underſtood by theſe degrees: By the common thermometers no intelligible notion can be formed thereof. A degree is properly a part of a known and determinate quantity, which taken a number of times, is exactly equal to the quantity, as a whole or integer to its parts. For inſtance, if a *Paris* inch is divided into twelve equal lines, each of them may be called a degree. And therefore in order to determine, in an intelligible manner, the degrees of expanſion and contraction, which a fluid matter undergoes in a thermometer by heat and cold; you are to divide the ſpace, which the fluid matter occupies in a determinate degree of heat and cold, into equal parts. Suppoſe the ſpace, which the fluid in a thermometer occupied in a known and determinate degree of heat or cold, conſiſted of one thouſand cubic lines: A man would talk very intelligibly, to call one ſuch cubic line a degree. If there were two ſuch thermometers in two different places, and the ſpace of the fluids had decreaſed in both about twenty cubic lines; this would be a ſure indication, that the degree of cold in both places was equal. But had the ſpace of the fluids decreaſed in the one place A ten, and in the other B twenty cubic lines: The degree of cold in the place A would be to that in B, as ten to twenty, or as one to two. Among the thermometers, on which the degrees are denoted in an intelligible manner, the principal are *Fahrenheit*'s, *Reaumur*'s and *De l'Iſle*'s.

1. In *Fahrenheit*'s manner, you mix up in winter weather, after a ſtrong froſt, grated ice with ſal armoniac, and place therein with its under veſſel a tube, filled either with ſpirit of wine, or with quickſilver, and mark the point where the quickſilver ſtands. On the table of the degrees, at which the tube is faſtened, you mark

this point with O. Then you ſet this tube with the under veſſel in water, which by the natural cold is changed into ice, and you mark the point where then the quickſilver ſtands. The ſpace between both theſe points is divided into thirty-two equal parts or degrees; of which the thirty-ſecond terminates at the point, at which the fluid ſtood, as the water was turned to ice. After this, you ſet the under veſſel of the tube in warm water, which you ſuffer gradually to boil. The point, at which the fluid, as for inſtance, quickſilver, remains ſtanding in the midſt of boiling water, is marked 212; as from it to the point of the quickſilver in frozen water are reckoned one hundred and eighty degrees. Laſtly, you let the quickſilver turn ſo hot over the fire, as to begin to boil. The point of its height is marked 600, the number of degrees being carried on from 212. Now in order to examine, whether a greater degree of cold be ſtill poſſible in nature, than that produced by grated ice, mixed up with ſal armoniack; you ſtill ſet off on the table of degrees 100, 200, and more ſuch degrees under O.

M. Amantons firſt learned from experience, that common water has attained the greateſt degree of heat, when it boils, after which it can acquire no greater, remain it ever ſo long over the fire, and be the fire too never ſo intenſe.

This he relates in his diſſertation on ſome properties of the air, in which he deſcribes his new thermometer. It is inſerted in the memoires of the academy of ſciences for the year 1702. *Taglini*, a profeſſor of philoſophy at *Piſa* has oppoſed an experience to *Amantons*'s propoſition; viz. that a greater degree of heat may be given water, on letting it boil ſtronger. But then we are to conſider, that water in the firſt boiling attains not the greateſt degree of heat. If you let it boil for a quarter of an hour, while *Fahrenheit*'s thermometer ſtands therein: The aſcended quickſilver continues ſtanding at one point, be the fire under the veſſel afterwards heightened to any degree at pleaſure. But at the ſame time you are alſo to regard the gravity and denſity of the air. In one and the ſame degree of the air's gravity and denſity, water too has one and the ſame degree of heat.

2. *Reaumur* filled his thermometer with ſpirit of wine, and ſet it in water, which he let freeze by art, on laying round the veſſel of water grated ice, mixed up with ſalt. He obſerved the point, at which the ſpirit of wine ſtood in the tube, on the water being by the artificial cold, ſkinned over with a film of ice, and allowed the ſpace, which the ſpirit of wine filled up to the ſaid point of freezing, one thouſand equal parts, each of which he called a degree. The place, at

which the ſpirit of wine, condenſed by the freezing, ſtood in the tube, was as near again to the ball, as to the upper end of the tube. The degrees were mutually equal; not as to the length of the tube, but as to the expanſion of the ſpirit of wine. If the volume of the ſpirit of wine, which in the artificial cold had one thouſand parts, was encreaſed about $\frac{1}{1000}$ part, the thermometer ſhewed one degree of heat. If the volume was encreaſed about $\frac{2}{1000}$ part, the thermometer ſhewed two degrees. The degrees were wrote on the table on both ſides of the tube. On the one ſide, as for inſtance, the right you write O, by which the freezing point is denoted. The firſt degree under that is called 1; the ſecond 2, and ſo on in numerical order. And thus is the row or ſeries of the degrees of deſcent, or condenſation. Above O were alſo wrote 1, 2, 3, up to 80. Theſe are the degrees of aſcent or expanſion. On the other ſide of the tube, to the left, you write at O, as the freezing point, 1000; the volume of the ſpirit of wine, ſtanding there in the artificial cold, having one thouſand parts. Immediately under that, is 999; under this, 998, &c. And hereby the degrees of fall were denoted. Above O to the left came 1001, 1002, 1003 up to 1080, as the degrees of aſcent. And thus the degrees to the right expreſs by the numbers 1, 2, 3, 4, &c. how much the ſpirit of wine has expanded above O, as the point of artificial freezing, and contracted under the ſame point. The numbers on the left ſhew the actual volume of the ſpirit of wine, that, in the artificial freezing, conſiſts of one thouſand equal parts. This volume is now diminiſhed by the encreaſing cold, and conſiſts of 999, 998, 997, &c. parts: again enlarged by the encreaſing heat, and conſiſts of 1001, 1002, 1003, up to 1080 degrees.

For theſe thermometers you are to take tubes and balls of ſufficient width or bore, in order to have the variations of heat and cold ſufficiently diſtinguiſhable thereon. The diameter of the tube may be between two or three lines and above, and that of the ball four inches and over. The length of the whole thermometer is between four and five feet.

The preparation thereof, as given by *Reaumur*, is deſcribed in the memoires of the academy of ſciences for the year 1730, and in thoſe for the year 1731. The graduation he executed by the following rules. For filling he had ſmall and great meaſures. A ſmall meaſure contains only ſo much ſpirit of wine, as to ſtand in the tube between three and four lines high. The great meaſures, which ſerve for diſpatch, differ in ſize.

Many hold twenty-five; many fifty; many one hundred ſmall meaſures. By means of theſe meaſures we may alſo know, how many ſmall meaſures are contained in the ball and tube to the point, at which the ſpirit of wine ſtands in the cold of freezing water, and conſequently by the number of theſe meaſures determine the 1000 parts of this volume. Suppoſe it contained one thouſand meaſures, ſuch a meaſure would be $\frac{1}{1000}$ part. A ſmall meaſure is a piece of a glaſs tube, blown up in the middle like an olive, both whoſe ends terminate in ſlender and real capillary tubes. The length is between fifteen and ſixteen lines, alſo quite two inches, and above: Such a meaſure is filled, ſo either the one end be dipt in ſpirit of wine, and the other ſucked at by the mouth, till the ſpirit has reached the tongue; or ſo the meaſure be plunged in the ſpirit quite above the olive, and thus allowed to riſe to the end of the other capillary tube. The upper end of the tube you keep ſhut with a finger; or, which is ſtill ſurer, with the tongue; and ſo you heave out the meaſure, without a ſingle drop eſcaping, fig. 4. plate XIV. A greater meaſure conſiſts of a pretty thick glaſs tube; between four and five inches long, with a ball, fig. 5. plate XIV. You obſerve, how many ſmall meaſures go to one ſuch greater, and mark with a thread on the tube the height, at which the fluid ſtands by a certain number of ſmall meaſures. Before you fill the thermometer with ſpirits, you mark on the tube nearly the place, where you think to have the freezing point, with a fine thread, tied round the glaſs. Now in order to graduate: You put into the tube of the thermometer by means of a funnel a meaſure of one hundred, alſo a greater, till the ball is full, and the fluid riſes up to the ſet point; and you fill the meaſure only with water. You ſeldom hit it with the meaſures, as that the ſurface of the water ſhall ſtand at the thread, being now ſomewhat above, again ſomewhat under it. But then you need only ſhift the thread a little up or down, till having an equal height with the ſurface of the water. It often happens that the ball is not full by the laſt meaſure of one hundred. And did you add one more thereto, the water would riſe too high in the tube. This you remedy by putting coarſe gravel or bits of glaſs into the tube, to fall into the ball, by which means the water riſes higher in the tube. If now the water ſtands at the point, at which you would have it; you pour out of the tube of the thermometer ſome of its water into a meaſure of twenty-five or thirty, till the meaſure is full. And thus under the point, which you have allotted for the freezing, you obtain an empty ſpace of twenty-five or thirty meaſures or degrees. This done, you faſten the thermometer with wire at a ſmall board, on which a paper is glued, on which you mark the degrees with neat ſtrokes. The firſt ſtroke is made at the place, where the ſpirit of wine is to ſtand in the cold of the freezing water. Then you make a ſtroke at the place of the empty ſpace of the tube, when you poured the water into a meaſure of twenty-five or thirty. And then you fill a ſmall meaſure, and empty it into the tube. And where the water then ſtands you make a ſtroke. Again you fill the meaſure, and pour the water into the tube. And where now the water ſtands, you again make a ſtroke. This you repeat ſo often, as the number of the degrees requires, that are to have place in the tube, and are to be marked on the glued paper. In this manner you come to have pure degrees, each indicating one and the ſame volume of matter, as you all along uſe one and the ſame meaſure for filling. As the water out of ſo ſmall a meaſure, as that to hold a degree, poured into the tube, runs down ſlowly into it, and always inclines to apply itſelf to the glaſs; ſuch a meaſure is filled with quickſilver. For, this remains not ſticking to the glaſs, but falls quick to the bottom, and forces up the water. In like manner the degrees are marked above the freezing point. Now after the board is graduated, the water with the gravel or bits of glaſs and quickſilver is done out of the tube and ball. The grains of ſand and bits of glaſs are laid by. For, they come again into the thermometer, after drying. The thermometer alſo is well dried. And when dry, you pour in ſo much ſpirit of wine, till it ſtands three or four degrees above the thread, which indicates the artificial freezing. You place the ball of the thermometer in a cylindrical veſſel of metal plate, that is ſomething wider than the ball. If the veſſel is ſo high, that its rim reaches the thread, which indicates the freezing point on the tube; the thermometer will be the more adapted directly to indicate the ſmalleſt changes of heat and cold, ariſing in the air. This veſſel is filled with water, and placed in a wider, and at leaſt as high a veſſel. The ſpace between the two veſſels you fill with fine ſtamped ice, which is mixed up with a good quantity of ſaltpetre, or ſal-armoniack, or ſea-ſalt. In order to accelerate the freezing, linnen cloths are laid over the icy matters. On theſe a layer of rubbed ice is laid, and that again covered with cloths. If the ſurface of the water is froze, the ſpirit is near the deepeſt point, to which in this degree of cold it can fall. And when you think it is almoſt as deep as it well can; and it ſtands under the marked freezing point; with a ſmall funnel you gradually put more ſpirit thereto, till it reaches the place of the thread. If the ſpirit of wine fall no farther, yet let the ice that was produced, melt again, in order to be able to take out the ball without danger. If the ſpirit put in remains ſtanding above the thread, you ſling a lead ball on a wire-thread, which you convey into the ſpirit. Some of it ſettles on the ball and wire. After repeating this for two or three times you gain your end. This circumſtance requires the greateſt attention. For, an error of $\frac{1}{4}$ or $\frac{1}{8}$ of a degree happening, runs through the whole degrees. After taking the thermometer out of the ice, it is hermatically ſealed. And for this purpoſe you ſet the ball of the thermometer in water, which you gradually heat. The ſpirit of wine riſes, and the air goes out at the open end. The air remaining behind muſt not be rarified quite too much. For otherwiſe, in a great degree of cold the air goes out of the ſpirit into the empty ſpace of the tube, and on the returning heat hinders the ſpirit in the riſing. You procure a moderate rarifaction, on ſtopping the upper aperture of the tube with a mixture of turpentine and wax, and with a varniſh drawn over beſides. Yet you may alſo ſeal the end of the glaſs at the lamp, without rarifying the air in the tube too much, on drawing out the end of the tube into a hollow tender thread, and then ſuddenly running or melting its end. Now all this being done, the thermometer is faſtened on the graduated board. The thread on the tube, which indicates the freezing point, comes to the ſtroke on the paper.

But, in two ſuch thermometers, in order to compare the degrees together; it is neceſſary, that the ſpirit in both be of one and the ſame ſort and goodneſs. For, were there in the one A a ſtronger than in the other B; A would indicate a greater degree of heat than B, tho' both ſtood in one and the ſame air. For, a ſtronger ſpirit may be more expanded and rarified by the heat than a weaker in one and the ſame degree of heat. *M. Reaumur* filled his thermometer with a ſpirit, whoſe volume in the cold freezing water had 400, and in the heat of boiling water 435. And dividing both numbers by 5, the firſt is to the ſecond, as 80 to 87. He put into a long-necked cucurbit or body four hundred ſmall meaſures of ſpirit, and marked the point of the neck, at which the ſpirit ſtood in the artificial freezing. Then he obſerved, how high the heat of boiling water would raiſe it. But the ſpirit boils long before the water boils. Conſequently it ſhould appear, that the extent-point, to which the ſpirit riſes, could not be determined. *M. Reaumur* got over this difficulty by the following

ing deviſe. As ſoon as the ſpirit heaved or bubbled up in the heat of the boiling water, he took the body or cucurbit out of the water. The bubbling ceaſed, and the ſurface of the ſpirit became level. He put the body again in the water. The ſurface of the ſpirit turned level on the ceaſing of the bubbling, but ſtood higher than before. This operation *M. Reaumur* continued ſo long, till the ſpirit in this alternate taking it out of the boiling water, and putting it in again, remained ſtanding at one point. This point he deemed the fixed extent-point of the greateſt degree of expanſion, which the heat of the boiling water could give to the ſpirit, without itſelf boiling. The ſpirit he uſed on this occaſion, was ſuch, as in the ſpoon in which it was fired, to leave no water behind, and alſo to fire gun-powder.

The bigger a ball filled with ſpirit, the longer time is neceſſary before the heat of the air can pervade to its centre. Now heat and cold in the air are ſubject to frequent quick variations. The bigger therefore the ball of a thermometer, the leſs adapted it is, to indicate the true quantity of the heat and cold of the air. The degree of heat ariſen in the air, may decreaſe before it has penetrated the entire ball. In like manner, the degree of the cold of the air may be diminiſhed before the inmoſt ſpirit in the ball has cooled in an equal degree. In order to obviate this defect, *M. Reaumur* adviſes, inſtead of the ball of a thermometer, to take a cylindrical box.

As the ſpirit of wine has froze in a great degree of cold, as in 1737 was experienced at *Tornea* in *Lapland*, you fill *Reaumur*'s thermometer with quickſilver inſtead of ſpirit.

In *Fahrenheit*'s thermometer, the ſpace of the quickſilver between the freezing point and the point of the heat of boiling water, conſiſts of one hundred and eighty degrees. For, the point at which the quickſilver ſtands in the cold of the water turned to ice, is marked 32; and the point at which it remains ſtanding in the heat of boiling water, 212. Now deducting 32 from 212, there remain for the ſpace between theſe two fixed points one hundred and eighty degrees. In *Reaumur*'s thermometer this ſpace is ninety degrees. For, a degree in *Reaumur*'s thermometer is equal to two degrees in *Fahrenheit*'s. As an example may ſerve the obſervation, which *M. Maupertuis* relates in his *Figure de la terre*, lib. iii. c. 2. ſect. 5. *M. Maupertuis*, and the other academicians, who were to meaſure a degree of the meridian at the north polar circle, propoſed to make experiments with a pendulum clock on the degree of gravity there. For this purpoſe it was neceſſary to keep up one and the ſame degree of heat in the apartment. They therefore hung at the ſides of the pendulum-clock, *Fahrenheit*'s and *Reaumur*'s thermometers. *Fahrenheit*'s was executed by *M. Prins*, and *Reaumur*'s was filled with quickſilver by the abbè *Nollet*. The obſervation was continued from *April* 6, 1737, for five days ſucceſſively at *Pello* a village in *Finland*. The degree of heat was kept up at ſuch a pitch, as that for thoſe five days and nights the ſpirit in *Reaumur*'s thermometer ſtood conſtantly between 14 and 15, and the quickſilver in *Fahrenheit*'s always between 60 and 62. The difference between 14 and 15 is = 1, and between 60 and 62 = 2. And therefore the ſpace 180, contained in *Fahrenheit*'s thermometer between the points of the greateſt, and leaſt degree of heat of the water, divided by 2; there come out ninety degrees for the ſpace between the ſaid points in *Reaumur*'s thermometer.

3. *M. Deliſle* towards the cloſe of the year 1733, began to execute a thermometer in a new method which he afterwards uſed as a ſtandard in adjuſting other thermometers. The method he uſed for the purpoſe, he read openly in the academy of ſciences at *Peterſburg* in 1733, and ſubjoined it, p. 269, ſeq. to his *Memoires pour ſervir a l' hiſtoire et au progres de l' aſtronomie; de la geographie, et de la phyſique.* This thermometer, conſiſting of a flaſk-like veſſel or cylinder,

and an annexed tube, he filled in the time of a very ſevere cold with pure mercury, and then placed it in water, which was gradually heated, and at laſt brought to boil. As the quickſilver was expanded by the heat, part of it ran out at the perpendicular ſtanding tube: And continued to run ſo long, till the water had attained the higheſt degree of heat of which it is capable: The tube the while remaining full of mercury quite to the upper aperture. The entire ſpace, which the quickſilver occupied in the heat of the boiling water in the cylinder and in the whole length of the tube, he divided in general into 100,000 equal parts, or equal ſpaces. Then he inquired, how many ſuch parts were contained in the tube alone, reckoning from the point, where the quickſilver had ſtood in the heat of the boiling water. This he diſcovered on weighing as well the quickſilver in the cylinder, as alſo the quickſilver in the tube quite to the ſaid height, each apart. For, as the ſum of both weights, or the weight of the quickſilver in the whole ſpace of the thermometer is to 100000 parts of this whole ſpace, ſo is the weight in the tube to the ſpace therein in a hundred thouſand parts. In this manner he made three great mercurial thermometers, which he exhibited in their natural dimenſions on a plate. On the tube of the firſt 2400 degrees are marked, ed, each of which is a hundred thouſand part, or a particle, 100000 of which make out the whole ſpace. On weighing the maſſes of quickſilver contained in the cylinder and tube of this thermometer, he found the whole ſpace to conſiſt of 54760 parts. In the great cold, at the time of the experiment, the quickſilver ſunk in the tube through a ſpace of 681 ſuch parts. Theſe 681 parts amounted to 1243 of the hundred thouſand parts, which was in general aſſigned the ſpace. For, 54760 : 100000 : : 681 : 1243. If the number 100000, which expreſſes the whole ſpace of the quickſilver, is divided by the number of ſuch hundred thouſand particles, as the degrees, by which the quickſilver in the tube falls in a certain degree of cold: The quotient ſhews, by how much the quickſilver in the thermometer is become denſer by the cold. Suppoſe it fallen down 2000 degrees in a certain degree of cold, it would be denſer by the fiftieth part; in regard 2000 is contained fifty times in 100000 parts. For, by as many parts, 100000 of which make out the whole ſpace, as the quickſilver ſubſides in the cold, by ſo many particles will the ſpace filled up before, be now empty. But by how many parts the ſpace filled up before, is now empty, by ſo many parts the denſity encreaſes. The firſt you find, ſo you divide 100000, as the whole ſpace, by the number of the degrees, by which the ſpace, in the ſubſiding of the quickſilver, is become empty.

After *M. Deliſle* had brought this principal or ſtandard thermometer to bear, he afterwards executed ſeveral others with leſs trouble; only that he examined, what ratio the ſpace of the tube had to the ſpace of the cylinder. He filled theſe thermometers with quickſilver, and placed them in warm water, which was gradually heated, and marked the place, which the quickſilver reached by the greateſt heat of the boiling water. After this, he ſet ſuch a thermometer along with the ſtandard thermometer in one and the ſame degree of cold of the air. And when pretty great, he divided the ſpace, through which the quickſilver, from the place which it had in the heat of the boiling water, to the place at which it ſtood in this degree of cold, into ſo many hundred thouſand particles, or degrees, as the ſtandard thermometer in this very degree of cold exhibited.

Deliſle's ſtandard thermometer is of very difficult execution. It is to be undertaken in a great degree of cold; which all the time the operation laſts, muſt remain unchanged. Now the degree of cold changes almoſt every hour. And therefore it is ſeldom we attain to that degree of certainty, that the diviſion of the degrees accurately coincides with the diviſion of the maſs of the quickſilver. We are therefore to pitch upon a certain degree of cold, which we know, continues all along one and the ſame; and then to compare the ſpace which the quickſilver in the thermometer occupies in this degree of cold, with the ſpace which this very quickſilver in the thermometer fills up in the heat of the boiling water. Turn the water of a river to ice when it will, the degree of cold by which the ice ariſes, is one time as great as the other. This has been found by many trials as well in the water of the *Neva*, as in the waters of *Siberia*. The experiments in the *Neva* were made by profeſſor *Joſias Weitbrecht*, of the academy of ſciences of *Peterſburg*, with a thermometer, which *M. Deliſle* adjuſted by his ſtandard thermometer, and whoſe internal ſpace to the point of the greateſt degree of cold, in which his ſtandard thermometer was made, he divided into 10000 parts. Theſe experiments made in the *Neva* are deſcribed in the *Commentarii Acad. Petropolit.* T. VII. p. 235, ſeqq. In *Siberia* profeſſor *Gmelin* in *November* and *December* 1737, and in *January* and *February* 1738, made the ſame experiments with all imaginable care; and every time obſerved one and the ſame degree of cold as well in running as ſtanding waters, when their ſurface is covered with ice. The quickſilver in *Reaumur*'s thermometers, which were made under the direction of *M. Deliſle*, ſtood every time at the 152d degree, when the balls of the thermometers were under the ice in the water, how great ſoever the degree of the cold of the air and ice might otherwiſe be. Profeſſor *Gmelin* relates this in the *Comment. Petropolit.* T. X. p. 303, ſeqq.

Profeſſor *Weitbrecht* has therefore pitched upon the degree of cold of the water turned to ice for determining a fixed point, at which the quickſilver in a thermometer remains at length ſtanding, when taken out of the heat of the boiling water, and always left to a leſs degree of heat of the water down to the leaſt thereof. Now as he hung the ſaid thermometer of *M. Deliſle* which was made by the ſtandard thermometer in the ſtream; the quickſilver remained ſtanding at the 152d degree, when the water of the *Neva* was turned to ice. He examined it as well with this as with another thermometer, at different times. The quickſilver ſtill remained ſtanding at this very degree. So that he held this degree, as a $\frac{152}{10000}$ particle of the whole ſpace in the thermometer, for the degree of cold, in which water turns to ice. But he came to ſuſpect this, when he examined this degree of cold by the other thermometers made after *Deliſle*'s ſtandard, the the ſtandard thermometer. In theſe the mercury remained ſtanding not at the 152d degree, though they hung in the very ſame water, whoſe degree of cold brought the mercury in the firſt thermometer to ſubſide to the ſaid degree. The difference amounted to one, two, and more degrees. He made the experiment in the preſence of *M. Deliſle*, when he hung his ſtandard thermometer along with his own, which was adjuſted by it, in the water of the frozen river. In his thermometers of *Deliſle*, which were adjuſted by quickſilver ſtood at the 152d degree, and in the ſtandard thermometer itſelf only at the 1495th. If inſtead of 100000 particles you aſſume 10000, 1495 will come to the ſame thing as 149$\frac{1}{2}$. For, 100000 : 10000 : : 1495 : 149$\frac{1}{2}$. And thus the difference conſiſted in 2 $\frac{1}{2}$ degrees. *M. Weitbrecht* therefore examined the thing by new thermometers, which he moſtly executed in *Deliſle*'s manner; only that he compared the ſpace in the tube of the thermometer between the place, at which the quickſilver ſtands in the heat of the boiling water, and between the place, at which it ſtands in the cold of the freezing, with the remaining ſpace in the thermometer. He proceeded in executing theſe thermometers, which he deſcribes in the *Comment. Petropolit.* T. VIII. in a twofold manner. In both ways he firſt of all weighed the empty thermometer. And in the firſt method, he filled the cylinder and a part of the tube with quickſilver, and weighed this maſs; but marked the place, at which it ſtood in the cold of the water turned to ice. Then he marked the place, to which it roſe by the expanſion in the heat of the boiling water. The way or ſpace between theſe limits of heat and cold, he meaſured out or divided into ten parts of a line, ſuch as ten lines make an inch, and twelve inches an *Engliſh* foot. After having meaſured this way, he put the thermometer again in water, which by the cold was turned to ice, and filled up the ſaid way or ſpace in the tube with quickſilver, and ſought the weight of this addition. In the ſecond method he filled the thermometer quite to the top, as it ſtood in water turned to ice, and weighed the whole maſs of the quickſilver, which the thermometer contained in this degree of cold. Then he conveyed the thermometer into warm water, and weighed the maſs, which by the heat of the boiling water was forced out of the tube. After this he ſet the thermometer again in water, which was turned to ice, and marked the place at which the ſubſiding mercury remained ſtanding. The entire ſpace in each thermometer he divided with *M. Deliſle* in general into 100000 equal parts. In the one thermometer which he called A, the mercury, which in the cold of the freezing water ſtood in the tube at the place A, weighed 1861 grains. Then he filled the tube full up to B. And then the whole maſs of the quickſilver weighed 1890 grains. So that the quickſilver in the ſpace AB, between the limits of the heat and cold, weighed 29 grains. The length of the ſpace conſiſted of 316 decimal parts of the line. The maſs 1861 contained therefore $98465\frac{1150}{1890}$ parts of 100000. For, 1890 : 100000 : : 1861 : $98465\frac{1150}{1890}$. The maſs 29 in the ſpace AB contained $1534\frac{740}{1890}$ parts of 100000. For, 1890 : 100000 : : 29 : $1534\frac{740}{1890}$. Did we incline ſo to lengthen the tube, as that it ſhould hold all the quickſilver; the length of the ſpace which 1861 grains filled up, would have had $20278\frac{14}{29}$ decimal parts of the line. For, 29 : 1861 : : 316 : $20278\frac{14}{29}$. The entire length of the whole maſs would have had $20594\frac{14}{29}$ decimal parts of the line. For, 29 : 1890 : : 316 : $20594\frac{14}{29}$. Of 100000 particles therefore, there come $98465\frac{36340}{59724}$ to the length, $20278\frac{14}{29}$ which 1861 grains would have filled up. For, $20594\frac{14}{29}$: 100000 : : $20278\frac{14}{29}$: $98465\frac{36340}{59724}$. And to the length of the ſpace

316, which the quickſilver between the limits of the heat and cold fills up, of 100000 particles, there come $1534\frac{23884}{59724}$. For, $20594\frac{14}{29}$: 100000 : : 316 : $1534\frac{23884}{59724}$.

If you divide the fraction $\frac{23884}{59724}$ by 316, you have $\frac{75}{189}$ a fraction of equal value. And thus of 100000 particles or ſmall parts, there come $1534\frac{75}{189}$ to the length of the ſpace AB. And putting 10000 for 100000, there come out $153\frac{1}{2}$ of ſuch 10000 particles for the quickſilver in the ſpace AB. For 100000 : 10000 : : $1534\frac{75}{189}$: $153\frac{1}{2}$.

Now *M. Weitbrecht* applied himſelf to examine, whether alſo in the other thermometers, the ſpace of the quickſilver, between the limits of the heat in the boiling water, and the cold in the freezing, would have $153\frac{1}{2}$ degrees, on giving the entire ſpace 10000 ſuch parts or degrees in general. He made five more experiments, and found every time a difference. The ſaid ſpace was,

In the firſt experiment	=	$153\frac{1}{2}$ degr.
In the II. ——	=	$148\frac{1}{5}$
In the III. ——	=	$161\frac{1}{2}$

In the IV. —— = 156 $\frac{1}{4}$
In the V. —— = 148 $\frac{3}{5}$
In the VI. —— = 149 $\frac{1}{50}$

This difference may ariſe from a ſmall error in the weighing. In the thermometer, which *M. Weitbrecht* had adjuſted by *Deliſle*'s ſtandard thermometer, and hung at the ſame time along with it in the water of the *Neva*, covered with ice, the quickſilver ſtood at the 152d degree, and in *Deliſle*'s at the 149th $\frac{1}{2}$. Inſtead of the 100000 parts he allowed only 10000 to the whole internal ſpace of the quickſilver. And on deducting 152, as the degree, which the quickſilver traverſes from the greateſt heat of the water down to the leaſt, from 10000; the ſpace in which the quickſilver, contracted or condenſed by the cold of the freezing water, is contained, conſiſts of 9848 ten thouſand particles. The quickſilver contained in this ſpace in the thermometer, which *M. Weitbrecht* calls A, weighed 1861 grains. By the proportion, which 9848 has to 10000, the maſs of the quickſilver of 1861 grains, with the other maſs in the ſpace AB, which the quickſilver runs through from the greateſt degree of heat of the water down to the leaſt, ſhould conſiſt of 1889 $\frac{3}{4}$ grains. For,

$$9848 : 10000 :: 1861 : 1889\frac{7128}{9848}.$$

And this fraction divided by 2462, is = $\frac{3}{4}$

nearly. But the weight of the whole maſs amounted to 1890 grains. So that $\frac{1}{4}$ of a grain in the weighing was given too much. Were the weight of the entire maſs juſt; the maſs, with which *M. Weitbrecht* filled up the ſpace AB between the limits of the leaſt and greateſt degree of heat of the water, ſhould weigh 28 $\frac{3}{4}$ grains. For, 10000 : 1890 : : 152 : 28 $\frac{7280}{10000}$. And this fraction divided by 2427, is = $\frac{3}{4}$ nearly. But the maſs in the ſaid ſpace weighed 29 grains. And thus its weight was aſſigned about $\frac{1}{4}$ too great. As the error is ſo ſmall; it appears, the diviſion of the way or ſpace, which the quickſilver traverſes from the greateſt degree of heat of the water down to the leaſt, into $\frac{152}{10000}$ of a particle or degree might be aſſumed as a rule, by which the degrees of heat and cold might be pretty accurately determined and judged of.

But if you aſſign $\frac{150}{10000}$ of a particle to the length of way, which the quickſilver accompliſhes, when carried from the greateſt heat of the water to the leaſt; the error is juſt as ſmall, and which may have ſlipt in, in the weighing; and conſequently we have in this diviſion juſt as good a rule for determining the degrees of the heat and cold. For, deducting 150 from 10000, there come to remain 9850 ſuch particles to the ſpace, which the quickſilver in the cylinder and tube occupies to the place, at which it ſtands in the cold of the freezing water. In this place the quickſilver in *Weitbrecht*'s thermometer, which was above called A, weighed 1861 grains. And thus by this reckoning there come 1889 $\frac{1}{3}$ grains to the whole ſpace. For, 9850 : 10000 : : 1861 : 1889 $\frac{335}{985}$. And this fraction divided by 335, is = $\frac{1}{3}$ nearly. The quickſilver in the whole ſpace weighed 1890 grains. So that the balance gave $\frac{2}{3}$ of a grain too much. And juſt by ſo much was the weight of the quickſilver in the ſpace A B, between the limits of the greateſt and leaſt degree of heat of the water, too great, when on weighing the whole maſs there had been no error committed. On the balance the quickſilver in the ſaid ſpace A B weighed 29 grains. But by the calculation it ſhould weigh only 28 $\frac{1}{3}$. For, 10000 : 1890 : : 150 : 28 $\frac{350}{1000}$, which fraction is = $\frac{1}{3}$ nearly, on dividing it by 350.

In *Deliſle*'s ſtandard thermometer, the ſpace of the quickſilver within the limits of the greateſt and leaſt degree of heat of the water, was $\frac{1495}{100000}$ of a particle, or ſmall part. And deducting 1495

from

from 100000, the remaining ſpace is 98505. Now had the quickſilver in this ſpace, in *Weitbrecht*'s thermometer A, weighed 1861 grains, it had only weighed 1889 $\frac{1}{4}$ grains in the whole ſpace. For, 98505 : 100000 : : 1861 : 1889 $\frac{24055}{98505}$. And the fraction divided by 24055, is $= \frac{1}{4}$. And thus the balance has given $\frac{3}{4}$ of a grain in weight too much. And juſt this the calculation ſhews, on ſeeking the error of the weighing in the maſs of mercury, which the ſpace AB, between the limits of the greateſt and leaſt degree of heat of the water, contained. 100000 : 1890 : : 1495 : 28 $\frac{25550}{100000}$ $\frac{1}{4}$.

As the error, which by the calculation, falls to the weighing the quickſilver, is every time very ſmall; whether you aſſign the ſpace which the quickſilver runs over, from the greateſt down to the leaſt degree of the heat of the water, in a thermometer, either 152 degrees, or 150, or 149 $\frac{1}{2}$: And ſo one is at a ſtand which of the three numbers to fix on for the ſaid ſpace. *M. Weitbrecht* ſought more accurately to determine the weight of the quickſilver, on uſing the hydroſtatical balance, deſcribed by *Graveſande* in his *Elementa Phyſices*, §. 271. He therefore continued to make experiments with three thermometers, uſing all the circumſpection poſſible;

but in the calculation found no agreement among the experiments; and the error, which in the weighing might have ſlipt in, in all the three numbers 152, 150 and 149 ½, conſiſted in a minutia, or very ſmall matter. The reaſon, why this error cannot be avoided, lies in the quickſilver. For, be the thermometer filled either in the cold or in the heat, you ſeldom ſucceed, to have the quickſilver ſtand at equal height with the aperture of the tube, and fully apply to the internal rim of the glaſs, as removing to a diſtance from the internal rim, and forming in the middle a ſmall eminence. And thus in the ſpace, which the quickſilver has traverſed from the greateſt down to the leaſt degree of heat of the water, there may very eaſily be a ſmall globule, and conſequently in the weight a third or half, or a whole grain, either too little, or too much. And as thus there are no hopes of coming to a perfect harmony in experiments: The queſtion is, which of the three numbers 150, 152, 149 ½ we are to pitch upon for the ſpace of the quickſilver between the greateſt and leaſt degree of heat of the water? The length of the ſpace remains one and the ſame, whether you divide it into 150, 152, or 149 ½ degrees. But the ſingle degrees in the one number differ in length from the ſingle degrees in the others. Yet that difference in thermometers, where one degree is ſcarce $\frac{3}{10}$ of a line, or $\frac{1}{2}$ of a line in length, is ſo ſmall as not to be diſtinguiſhable by the eye. If, for inſtance, in the number 150, the length of a degree is $= \frac{3}{10}$ of a line; ſo a degree in the number 152 is about $\frac{1}{250}$ particle of a line leſs. For, both numbers repreſent one and the ſame length of the ſpace between the limits of the greateſt and leaſt degree of heat of the water. Now if a degree in the number 152, as well as a degree in the number 150, was $\frac{3}{10}$ of a line; the ſpace which the number 152 denotes, would be about $\frac{6}{10}$ of a line too long. For, multiplying both numbers by $\frac{3}{10}$; the number 150 is $= \frac{450}{10}$, and the number 152 $= \frac{456}{10}$. And therefore for the number 152 to denote no longer a ſpace than the number 150; each $\frac{1}{152}$ of a particle muſt differ in quantity from a $\frac{1}{150}$ of a particle, and be by ſo much leſs, that the ſmall quantities, wanting to the 152 particles, ſhall make out $\frac{6}{10}$ of a line in 150 degrees. Now dividing 150 by $\frac{6}{10}$, the quotient ſhews, what part of the line comes to $\frac{1}{150}$ of a particle, or to a degree. But in order to divide 150 by $\frac{6}{10}$, you reverſe the fraction, and multiply the fraction $\frac{10}{6}$, thence ariſing, by $\frac{150}{1}$. The product, thereby coming out, is $= \frac{1500}{6}$. And dividing the numerator by the denominator, the quotient is $= 250$. And thus a degree in the number 150 is about $\frac{1}{250}$ of a particle of a line greater than a degree in the number 152. This difference remains undiſtinguiſhable to the eye: Neither would it be diſtinguiſhable, though in the number 150 a degree was = $\frac{1}{2}$ line. For, as the number 152 denotes no greater length than the number 150, you have 2 half lines, that is, one whole, to be ſhared out among 150. And ſo to one degree there comes $\frac{1}{150}$ of a particle of a line. And on comparing the number 150, in which a degree is equal to $\frac{3}{10}$ of a line, with the number 149$\frac{1}{2}$; a degree in the number 150 is about $\frac{1}{1000}$ of a particle of a line leſs than a degree in the number 149$\frac{1}{2}$. Both numbers differ about $\frac{1}{2}$ degree, and conſequently about $\frac{3}{20}$ particle of a line, from each other, when a whole degree is $\frac{3}{10}$ of a line. For, a fraction is the half of another, when having the ſame numerator therewith, its denominator is twice as great as that of the other. So that $\frac{3}{20}$ is to be ſhared out among 150 degrees; that is, 150 to be divided by $\frac{3}{10}$. And if thus, according to the rule of diviſion in fractions, $\frac{150}{1}$ be multiplied by $\frac{20}{3}$, the product is = $\frac{3000}{1}$. And therefore dividing the numerator by the denominator, the quotient is = 1000. If in the number 150 a degree is = $\frac{1}{2}$ of a line, ſuch a degree is about $\frac{1}{600}$ of a particle of a line leſs than a degree in the number 149$\frac{1}{2}$. For, the half degree, about which both numbers differ mutually, makes out $\frac{1}{4}$ of a line. If therefore $\frac{150}{1}$ be multiplied by $\frac{4}{1}$, the product is = $\frac{600}{1}$, and thus the quotient = 600. Beſides, that a degree in the number 150 differs inſenſibly in quantity from a degree in the numbers 152 and 149½, the diviſion of the ſpace, which the quickſilver runs over in the tube of the thermometer from the greateſt degree of heat of the water down to the leaſt, comes neareſt to the experiment by *Deliſle*'s ſtandard thermometer, on which this very ſpace is marked 149½ degrees. And thus we have reaſon to prefer the diviſion of this ſpace into 150 degrees to both the others, viz. 152 and 149½.

M. Weitbrecht therefore in his diſſertation *de Thermometris concordantibus*, contained in the *Comment. Petropol.* T. VIII. §. 16. gives the following direction for executing thermometers mutually harmonious. Take a glaſs tube, at which below is a ſomewhat wide cylinder. Its diameter may be 3, 4, alſo five lines, and the length from 2 to 3 inches. The diameter of the tube may be from $\frac{1}{5}$ to $\frac{3}{10}$ of a line, and the length from 10 to 12 inches. This inſtrument you fill with pure quickſilver, as far as you will, and you ſet it in boiling water, and then in freezing: And you mark as well the point, which the quickſilver reaches in the heat of the boiling water, as the point, at which it remains ſtanding in the cold of the freezing water. The length of the ſpace between both theſe points you ſet off on a ſurface at the thermometer, which you may call the diviſion-table; and you divide the ſaid length into 150 equal parts or degrees. You begin the reckoning at the point, at which the quickſilver ſtood in the heat of the boiling water. And where 150 ſtands, there is the point, at which the quickſilver ſtands in the leaſt heat of the water, as it begins to turn to ice. Under this point the diviſion begun is ſo far carried on, as the length of the tube admits. Did you chuſe to carry on the diviſion above 200 up to 300, you are ſo to order and fill the thermometer, that the quickſilver in the cold of freezing water ſhall reach to about the middle of the tube. The circumſtances neceſſary to be obſerved in executing the inſtruments, in filling them and preparing the diviſion-table, are recounted §. 17. ibid.

As the cavity of the glaſs cylinder turns larger by the heat of the boiling water, and leſs by the cold of the freezing: A doubt ariſes, whether the ſpace which the quickſilver occupies in the thermometer in the greateſt degree of the heat of the water, is accurately and in fact, to the ſpace, which it fills up between the limits of the greateſt and leaſt degree of the heat of the water, as 10000 to 150? *M. Weitbrecht* owns, that this cannot be affirmed with truth: But then he hints, that we only want to know the ratio of both the determined ſpaces to each other, in ſo far as the quickſilver is in an inſtrument, whoſe internal ſpace is variable. And here you may conſider profeſſor *Kraft*'s *Diſſertatio experimentalis de Thermometris*, which is contained in the *Comment. Petropolit.* T. IX. p. 241.

§. 124. And thus in theſe three thermometers, that of *Fahrenheit*, *Reaumur* and *Deliſle*, having determined a ſpace between two known and fixt points, and divided it in each thermometer into certain aliquot or equal parts, called degrees, you may now compare theſe degrees in the three thermometers with each other. The ſpace between both the points in *Deliſle*'s, conſiſts of 150, and in *Reaumur*'s of 90 degrees. And thus 5 degrees in *Deliſle*'s make 3 in *Reaumur*'s; and conſequently 3 in *Reaumur*'s make 5 in *Deliſle*'s. For,

$$150 : 90 :: 5 : 3, \text{ and}$$
$$90 : 150 :: 3 : 5.$$

In *Fahrenheit*'s thermometer the ſaid ſpace conſiſts of 180 degrees, §. 159. And thus 5 degrees in *Deliſle*'s make 6 in *Fahrenheit*'s, and conſequently 6 in *Fahrenheit*'s make 5 in *Deliſle*'s. For,

$$150 : 180 :: 5 : 6, \text{ and}$$
$$180 : 150 :: 6 : 5.$$

§. 125. In order to reduce a number of *Reaumur*'s degrees, as for inſtance, 32, into thoſe of *Deliſle*, you are to multiply this number 32 by $\frac{5}{3}$. For, 3 of *Reaumur*'s degrees give 5 of *Deliſle*'s. So that by the rule of three you are to multiply the third number, as here 32, by the ſecond 5, and divide the product by the firſt. That is, $\frac{5}{3}$ x 32. The product of which is = $\frac{160}{3}$ = $53\frac{1}{3}$. And thus 32 of *Reaumur*'s degrees give $53\frac{1}{3}$ of *Deliſle*'s. In order to reduce a number of *Deliſle*'s degrees, as for inſtance, $53\frac{1}{3}$, into *Reaumur*'s; this number $53\frac{1}{3}$, you are to multiply by $\frac{3}{5}$. For, 5 of *Deliſle*'s degrees give 3 of *Reaumur*'s. And that is $\frac{3}{5}$ x $53\frac{1}{3}$. Now $53\frac{1}{3}$ was equal to $\frac{160}{3}$. And therefore you ſet down $\frac{3}{5}$ x $\frac{160}{3}$. The product of which is = $\frac{480}{15}$. And dividing the numerator by the denominator, the quotient ſhews, that $53\frac{1}{3}$ of *Deliſle*'s degrees make 32 of *Reaumur*'s. And having to reduce a number of *Fahrenheit*'s degrees, as ſuppoſe 60, to thoſe of *Deliſle*'s, you are to multiply this number by $\frac{5}{6}$. And thus you ſet down $\frac{5}{6}$ x 60. For, 6 of *Fahrenheit*'s degrees give 5 of *Deliſle*'s. The product of $\frac{5}{6}$ x 60 is = $\frac{300}{6}$. And dividing the numerator by the denominator; the quotient ſhews, that 60 of *Fahrenheit*'s degrees are = 50 of *Deliſle*'s. And thus to reduce a number of *Deliſle*'s, as 50, into *Fahren-*

heit's, you are to multiply this number 50 by $\frac{6}{5}$. And thus $\frac{6}{5}$ x 50 = $\frac{300}{5}$ = 60.

§. 126. In theſe three thermometers if the freezing point was marked O; and the degrees of heat reckoned upwards from O, and thoſe of cold downwards from O: In reducing the degrees of the one into thoſe of the other no further trouble would be neceſſary. As ſuppoſe the ſpirit of wine, or the mercury ſtood in *Reaumur*'s thermometer 32 above O, it is evident from the product of $\frac{5}{3}$ x 32, that the quickſilver in *Deliſle*'s muſt ſtand 53$\frac{1}{3}$ above O, ſuppoſing both thermometers expoſed to the ſame degree of heat. But the freezing point in *Reaumur*'s thermometer is marked O, and in *Deliſle*'s 150. In *Reaumur*'s you reckon the degrees of heat upwards, going up from O; and in *Deliſle*'s downwards, in the reckoning going down from the point of the greateſt degree of heat of the water. And therefore to reduce a degree of *Reaumur*'s above O to one of *Deliſle*'s; *Reaumur*'s degree muſt be deducted from 150. For, the degrees above O in *Reaumur*'s approach to the point of the greateſt heat of the water. And even this happens, on deducting a number of degrees from 150. In order to reduce a degree of *Reaumur*'s under O into one of *Deliſle*'s, you muſt add the degree of *Reaumur*'s to 150. For in both thermometers the degrees under O indicate a greater degree of cold than the cold of the freezing water. Now as in *Deliſle*'s the cold of freezing water is denoted by 150; you have to add thereto the degrees in *Reaumur*'s thermometer under O, after reducing them into thoſe of *Deliſle*'s. Profeſſor *Heinſius* long ſince deviſed the following formula for the purpoſe,

$$I = 150 \mp \tfrac{5}{3} \times R.$$

I denotes a degree of *Deliſle*'s, and R one of *Reaumur*'s, and the ſign —, ſubſtraction; the ſign +, addition. You put the ſign —, when *Reaumur*'s degree is above O, and the ſign +, when under O. As, if R = 32 above O; then $I = 150 - \frac{5}{3} \times 32 = 96\frac{2}{3}$. For, $\frac{5}{3} \times 32 = \frac{160}{3}$. In order to ſubſtract this number from 150, you turn 150 into the fraction $\frac{150}{1}$, and reduce both fractions to one denomination, by multiplying the firſt fraction $\frac{150}{1}$ by the denominator of the ſecond 3; and the ſecond fraction $\frac{160}{3}$ by the denominator of the firſt 1; and you have the fractions $\frac{450}{3}$ and $\frac{160}{3}$. And deducting the laſt from the firſt, there remains $\frac{290}{3}$, and dividing the numerator by the denominator, the quotient is $96\frac{2}{3}$. If R under O was = 21, I would be $= 150 + \frac{5}{3} \times 21 = 185$.

In order to find from a degree of *Deliſle*'s I a degree of *Reaumur*'s R; you are firſt to reduce that of *Deliſle*'s to that of *Reaumur*'s. If this reduced degree is above the freezing point, you muſt deduct it from 90 degrees of *Reaumur's*. For, in *Deliſle's* thermometer the degrees are reckoned downwards. So many ſuch degrees therefore as are reckoned in *Deliſle's*, ſo many you take from 90 degrees in *Reaumur's* thermometer. Profeſſor *Heinſius* has therefore given the following formula,

$$R = 90 - \tfrac{3}{5} \times I$$

As if the degree of the heat $I = 110$; R is $= 90 - \tfrac{3}{5} \times 110 = 24$.

If *Deliſle's* degree is under the freezing point, the number conſiſts of the degrees above, and of thoſe under the freezing point 150. If therefore this number is reduced to the degrees of *Reaumur's*; theſe in like manner conſiſt of the degrees above and under the freezing point. But in *Reaumur's* the degrees of cold are reckoned without the degrees above the freezing point. So that you have to deduct 90 degrees from the reduced degrees, ariſing from *Deliſle's* degrees. As, if $I = 185$; $R = \tfrac{3}{5} \times 185 - 90 = 21$.

If *Deliſle's* degrees are under the freezing point, you need alſo only deduct from them the number 150. And thus you have the bare number of *Deliſle's* degrees under the freezing point; as, $185 - 150 = 35$. And then theſe 35 degrees are reduced to *Reaumur's*, and thus give 21 of *Reaumur's*. For $5 : 3 :: 35 : 21$.

In *Fahrenheit*'s thermometer, the ſpace from the point of the cold, produced with ice and ſal-armoniac, to the point of the heat of boiling water, is divided into 212 degrees; which are equal to $176\frac{2}{3}$ of *Deliſle*'s. For, 6 : 5 : : 212 : $176\frac{2}{3}$. In *Fahrenheit*'s thermometer the degrees above O are reckoned upwards from O. In *Deliſle*'s you go downwards in reckoning. Having therefore a degree above O in *Fahrenheit*'s, and willing to know what degree it makes in *Deliſle*'s, you are to reduce it to *Deliſle*'s degrees, and deduct it from $176\frac{2}{3}$. Whereas having in *Fahrenheit*'s thermometer a degree under O, and inclining to know what degree it makes in *Deliſle*'s, you are to reduce it to *Deliſle*'s, and add it to $176\frac{2}{3}$. For, theſe $176\frac{2}{3}$ degrees, ſtanding in *Deliſle*'s thermometer at the point, which in *Fahrenheit*'s is marked O, are carried on farther under O. And thus you are to add to them the degrees, which in *Fahrenheit*'s ſtand under O. The formula therefore given by profeſſor *Heinſius* is thus,

$$I = 176\tfrac{2}{3} \mp \tfrac{5}{6} \times F.$$

The ſign of ſubſtraction — holds, when *Fahrenheit*'s degree is above O. As, if F = 80 above O; I is $= 176\frac{2}{3} - \frac{5}{6} \times 80 = 110$. The ſign of addition + takes place, when *Fahrenheit*'s degree is under O. As, if F = 58 under O; I is $= 176\frac{2}{3} + \frac{5}{6} \times 58 = 225$.

If a degree of *Deliſle*'s is given, and you want to know, that anſwering to it in *Fahrenheit*'s; you are firſt to reduce *Deliſle*'s to *Fahrenheit*'s by the ratio that is between *Deliſle*'s and *Fahrenheit*'s degrees §. 125; and then ſubſtract the number thence ariſing from 212. For, in *Deliſle*'s thermometer you reckon from the point of the greateſt heat of the water downwards; and in *Fahrenheit*'s upwards to this point. Now ſo many degrees as are reckoned downwards, ſo many are abated of thoſe reckon'd upwards. And therefore you are to deduct *Deliſle*'s degrees, reckoned downwards, and reduced to *Fahrenheit*'s degrees, from *Fahrenheit*'s 212. From a given degree of *Deliſle*'s I to find that of *Fahrenheit*'s F, profeſſor *Heinſius* gives this formula,

$$F = 212 - \tfrac{6}{5} \times I.$$

As, if $I = 110$, F is $= 212 - \frac{6}{5} \times 110 = 80$. If *Deliſle*'s is greater than $176\frac{2}{3}$; 212 is deducted from $\frac{6}{5} \times I$. And the remainder ſhews the degrees, that aſcend above the number 212, and thus are under O. As, if $I = 225$, F is $= \frac{6}{5} \times 225\, I - 212 = 58$, under O.

From the obſervations made on the degrees of heat and cold in different parts of the earth, either with *Fahrenheit*'s, *Reaumur*'s, or *Deliſle*'s thermometer, profeſſor *Heinſius* has formed a table; in which, peculiarly remarkable inſtances of heat and cold are exhibited throughout by the graduation of *Deliſle*'s thermometer. On which in the year 1746, *May* 5, he read a lecture in the library of the univerſity of *Lipſick* before the young princes of *Saxony*, *Frederick Chriſtian*, and *Xaverius*.

Greateſt Degree of HEAT.

Place of obſervation, alſo ſome remarkable degrees.	Latitude of the place. Degr.	Min.	Time of obſervation N. Stile. Year	Mon.	Day.	Degree of the thermometer.
Boiling water.	—		—			0
The *Prudel* water in the bathing-tub at the *Caroline* bath.	—		—			$41\frac{3}{4}$
The new Spring-water.	—		—			$62\frac{1}{4}$
The *Muhlen* bath.	—	—	—		—	$87\frac{3}{4}$
Senegal at the mouth of the *Niger*, on the weſtern coaſt of *Africa*.	16	0 North	1738	*April*	12	$86\frac{1}{4}$
Aleppo in *Syria*.	35	45 N.	1736	*Sept.*	8	$93\frac{3}{4}$
Pondichery on the coaſt of *Coromandel*, *E. Indies*.	11	30 N.	1737	*June*	7	$95\frac{5}{8}$
Heat, with which chickens are hatched.	—		—			$96\frac{2}{3}$
Leipſick.	51	22 N.	1748	*July*	13	$99\frac{1}{2}$
Turin.	44	50 N.	1739	*June*	24	100
Caroline bath.	50	10 N.	1751	*July*	27	$101\frac{1}{2}$
Paris.	48	50 N.	1736	*July*	30	$100\frac{5}{9}$
St. Domingo in *Hiſpaniola*.	18	0 N.	1735	—		$100\frac{5}{9}$
Utrecht.	52	12 N.	1739	*July*	30	$102\frac{1}{2}$
Peterſburg in *Ingermanland*.	60	0 N.	1738	*June*	14	103

Greateſt Degree of HEAT.

Place of obſervation, alſo ſome remarkable degrees.	Latitude of the place. Degr.	Min.	Time of obſervation. N. Stile. Year.	Mon.	Day.	Degree of the thermometer.
The iſle *de Bourbon* on the eaſtern coaſt of *Madagaſcar.*	22	0 South	1734	*Jan.*	24	103$\frac{1}{3}$
Sylanche on the coaſt of *Peru* in *America.*	0	0	1736	*May*	16	103$\frac{1}{3}$
Bay *Antongil* on the eaſt coaſt of *Madagaſcar.*	16	0 S.	1733	*Jan.*	15	105
Algiers in *Africa.*	36	49$\frac{1}{2}$ N.	1736	*July*	28	105
Berlin.	52	33 N.	1732	*May*	27	105
Monte Chriſti on coaſt of *Peru.*	1	1 S.	1736	*Mar.*	21	106
Under the æquator in a ſhip at Sea.	0	0	1732	*Feb.*	20	106$\frac{2}{3}$
Under the æquator in a ſhip at ſea.	0	0	1735	*May*	24	110
Puerto vejo on the coaſt of *Peru.*	0	0	1736	*Mar.*	30	110$\frac{5}{6}$
Nerczinſk in *Siberia*, on the *Chineſe* borders.	51	56 N.	1735	*July*	25	112
Upſal in *Sweden.*	59	51$\frac{2}{3}$ N.	1739	*July*	12	119$\frac{1}{6}$
Quito in *Peru.*	0	13 S.	1736	*June*		120$\frac{5}{6}$
Common and mild ſummer heat.	——		——			122

The

The leaſt Degree of Heat, or the greateſt Degree of Cold.

Place of obſervation, alſo ſome remarkable degrees.	Latitude of the place.		Time of obſervation.			Degree of the thermometer.
	Degr.	Min.	Year.	Mon.	Day.	
The iſle *de Bourbon* on the eaſtern coaſt of *Madagaſcar.*	22	0 S.	1734	*Aug.*	22	$116\frac{2}{3}$
Pondicherry.	11	30 N.	1737	*Nov.*	26	$120\frac{5}{6}$
Senegal.	16	0 N.	1738	*April*	15	$126\frac{2}{3}$
Gualea on the coaſt of *Peru.*	0	0	1736	*June*	2	$128\frac{1}{3}$
Cadiz in *Spain.*	36	$33\frac{1}{2}$ N.	1737	*Jan.*	8	$131\frac{2}{3}$
Algiers.	36	$49\frac{1}{2}$ N.	1736	*Jan.*	9	$131\frac{2}{3}$
Temperate in the deep cave of the obſervatory at *Paris.*	———		———			133
Jeruſalem.	31	50 N.	1736	*Mar.*	30	$136\frac{2}{3}$
Quito in *Peru.*	0	13 S.	1736	*June*		$136\frac{2}{3}$
Freezing water.	———		———			150
Diarbeker on the *Tiger*, on the borders of *Perſia.*	37	30 N.	1736	*Nov.*	20	150
Padua in *Italy.*	45	28 N.	1730	*Dec.*	23	154
On the mountain *Pichincha* near *Quito* in *Peru.*	0	11 S.	1736	———		$156\frac{2}{3}$
Bagdat in *Aſſyria.*	33	15 N.	1737	*Jan.*	31	$156\frac{2}{3}$
Bourdeaux.	44	$50\frac{1}{2}$ N.	1740	*Feb.*	25	$160\frac{5}{6}$
London.	51	31 N.	1740	*Jan.*	5	$166\frac{2}{3}$
Paris.	48	50 N.	1740	*Feb.*	25	$167\frac{1}{2}$
Paris.	———		1754	*Feb.*	7	$169\frac{7}{12}$
Paris.	—	—	1709	———		$175\frac{5}{6}$
Lipſick.	51	22 N.	1748	*Mar.*	7	$176\frac{1}{2}$
Mount *Cenis* under the *Alps*, on the road from *Turin* to *France.*	———		1740	*Feb.*		$176\frac{2}{3}$

The leaſt Degree of Heat, or the greateſt Degree of Cold.

Place of obſervation, alſo ſome remarkable degrees.	Latitude of the place. Degr. Min.	Time of obſervation. Year Mon. Day.	Degree of the thermometer.
In *Iceland* from adjuſting *Fahrenheit*'s thermometer.	65 N.	1709 ——	176⅔
Leyden.	52 17 N.	1740 *Jan:* 11	177½
Berlin.	52 33 N.	1740 *Feb.* 7	183½
Wittenberg.	51 48 N.	1740 *Jan.* 11	185
Dantzick.	54 22 N.	1740 *Jan.* 11	187
Upſal in *Sweden.*	59 51⅔ N.	1740 *Feb.* 5	192
Peterſburg.	60 0 N.	1740 *Feb.* 5	201
Caſan.	55 44 N.	1733 *Dec.* 28	201
Nerczinſk in *Siberia.*	51 56 N.	1736 *Jan.* 20	206
Irkutſk in *Siberia.*	52 17 N.	1735 ——	207
Fahrenheit's artificial cold from mixing ſpirit of nitre and ſtamped ice. *Vid. Boerhav.* Chym. T. I. p. 147. Edit. *Leipſ.*	——	——	210
Tornea in *Lapland.*	65 51 N.	1737 ——	212
Kiachta in *Siberia* on the *Chineſe* borders.	50 20 N.	1736 ——	225
On the *Riphean* mountains between *Werchaturia* and *Solikamſk* in *Ruſſia.*	— 59½ N.	1742 *Dec.*	238
Kirinſkoi-Oſtrog on the *Lena* in *Siberia.*	57 47 N.	1737 *Dec.* 8 1738 *Jan.* 20	270 275

In order with accuracy to know the degrees of heat and cold in different countries, and ſeaſons of the year, it is neceſſary that the obſervers ſo place their thermometers in the free air to the north, that the ſun at no time ſhall ſtrike thereon. And in order to give an account of obſervations, it is alſo neceſſary to remark, whether adjoining walls reflect the ſun's rays or no; and whether the thermometer ſtands in the firſt, ſecond or third ſtory.

§. 127. To what degree ſolid bodies, in particular metals, may expand by fire, the pyrometer ſhews, an invention of *Muſchenbroeck*'s, deſcribed in his commentary on the *Tentamina Florentina*, P. II. p. 112. ſeq. with the many experiments made with this fire-gage. This pyrometer he has ſo ordered, that an octagonal rod of metal, in form of a parallelopepid, in extending, which is cauſed by a lamp-fire burning under it, at the ſame time moves an index on a ſheeve or circle, which is divided into 360 degrees, one degree forwards, when the extended length of the metal is to a *Rhinland* inch only as 1 to 12500. The degrees on the circle are ſo large, that they may be plainly diſtinguiſhed, when the index advances only $\frac{1}{2}$ degree, and conſequently the rod is lengthened about $\frac{1}{12500}$ particle of an inch. For, a whole degree denoting $\frac{1}{12500}$; a half denotes $\frac{1}{25000}$.

So that this pyrometer may be uſed for a thermometer. The experiments were made with ſix rods. Each in length 5 $\frac{8}{10}$ inches, and on both ſides in thickneſs $\frac{3}{10}$ inch. One was of iron, the ſecond of ſteel, the third of copper, the fourth of braſs, the fifth of tin, and the ſixth of lead. Iron was the leaſt lengthened, ſteel more, and lead moſt of all; and you may have either one or more lamps burning under the rods.

M. Muſchenbroeck, intending to examine, whether the degree of the heat in boiling water had its fixed limits, for that end encompaſſed the tin rod with a tin box, and poured into it boiling water at the time the air, in which the pyrometer ſtood, was ſo cold, that the fluid in *Fahrenheit*'s thermometer ſtood at 32 degrees. He kept the water conſtantly boiling by the fire of the underſet lamps. The tin rod at length was extended 102 degrees, each of which is $\frac{1}{12500}$ of an inch. But farther the length extended not, tho' the boiling was continued a long time by the fire. The entire rod was $\frac{58}{10}$ of an inch in length. And being now lengthened $\frac{102}{12500}$ particles of an inch, it was encreaſed in its whole length $\frac{1}{710}$. For $\frac{102}{12500}$ is to $\frac{58}{10}$, as 1 to 710. If this rod of tin or lead were 7100 lines, or 59 $\frac{2}{12}$ feet long, and came out of the cold of freezing water into a degree of heat, equal to that of boiling water, it would be lengthened about a whole inch. For, if the rod of 58 lines long is lengthened to 102 degrees; a rod of the ſame thickneſs, in length 7100 lines, is lengthened 12486 degrees. The laſt number differs from 12500, and the parts of a whole inch, only about 14. Conſequently, the degrees 12486 ſhew, that the intire length of the rod is increaſed nearly about an inch. If this rod lay in a heat of ſun, equal to the third part of the heat of the boiling water, its length therein would increaſe about $\frac{1}{3}$ of an inch.

CHAP. III.

Of Exciting Fire.

§. 128. AMONG all the known matters of the earth there is none in which fire is not contained. This included fire may be brought into motion, as well with, as without fire, by rubbing; whereby it comes to diſcover itſelf to our ſenſes. Bodies mutually rub, ſo in their motion, they touch and withſtand each other, §. 25. Which is a thing quite manifeſt in the parts of ſome bodies. But in others, the parts which mutually rub, and thereby excite their fire, are ſo ſmall, as neither they nor their rubbing, can be diſtinſtuiſhed by the eye. By the manifeſt rubbing, as well between two firm or ſolid bodies; as two pieces of wood, two metals, wood and metal; as between a ſolid and a fluid; as the air, and a ball ſhot thro' it, fire may be excited. A like effect may alſo ariſe by the concealed rubbing, that happens partly between two fluids, as water and ſpirit of nitre, vitriol and ſpirit of wine; partly between a fluid and a ſolid; as lime and water, pyrophorus and air, iron and aqua-fortis. Select examples of fire ariſing by both kinds of rubbing, you find in Profeſſor *Kraft*'s *Theoretical Phyſics*, §. 340, 345.

§. 129. If the parts of a body are ſo finely reſolved by the fire, as in the manner of a fluid matter, to move and mount up with a ſhining appearance; theſe parts we call *flame*; and what in a body turns to flame, the *phlogiſton*. But if theſe viſible and aſcending parts ſhine not in their ſeparation; they are called *ſmoke*. If the parts of the ſurface of a fiery or ignited body ſhines, but ſeparate not in the manner of flame; they are called *glowing*. Thoſe matters, which by the fire reſolve into a flame, are called *combuſtible*; and by the ſeparating of the flame, come gradually to be conſumed. In order to maintain or continue ſuch a fire, which as well conſumes its body, as it is itſelf diſſipated; you are to add a combuſtible matter, which in like manner reſolves by the fire, and occupies the place of the particles of fire gone off. Such a matter is called the *fuel of the fire*. If the fire turns a ſolid body to a fluid; this action of the fire is called *melting*. If after the reſolution, produced by the fire in a body, nothing but ſmall fixed particles remain behind, which have a ſmall, and almoſt unobſervable connection among each other, theſe we call *aſhes:* And the action of the fire, by which they ariſe, *calcination*, or *incineration*.

As the parts of flame have a tendency to remove from the unreſolved parts; ſo the flame cannot ſubſiſt, unleſs the air by its gravity and ſpring act againſt the burning body. Hence flame dies or is extinguiſhed, on withdrawing from it the ambient air. Alſo the air muſt have a free draught, for flame to laſt. The upper parts thereof are finer than the under, and thus may be more compreſſed than theſe; ſo that by the preſſure of the air, the flame muſt become ſlender and pointed. The outmoſt parts on a glowing ſurface have in like manner a tendency to expand themſelves. If this tendency finds no ſufficient reſiſtance, the glow vaniſhes. And therefore glowing bodies ſooner ceaſe to glow in vacuo, than in air. Farther, from this we may explain, why neither by ſnapping the lock of a gun; nor by the rays condenſed by a burning glaſs, can gun-powder be fired in vacuo, ſo as to flame or flaſh. On ſnapping the lock, the particles of fire contained in the flint and ſteel, are indeed, brought into motion: But they alſo inſtantly die, as no air preſſes againſt them. And therefore having reached the gun-powder, their force is either too weak, or quite uneffectual. At times, indeed, a faint light appears; but this is owing to the air ſtill remaining, having had ſome effect. If the focus of a burning-glaſs falls on the gun-powder; the grains melt, and ſend forth ſmoke but no flame; which therefore cannot ariſe, as the air does not ſo compreſs the fine particles from which flame otherwiſe ariſes, quite round, as to be able to form a fluid maſs. Smoke there muſt be; as in gun-powder partly air, partly other matters are contained, whoſe reſolution and admixture, interrupt the motion of light.

§. 130. From an incombuſtible body certain particles, that belong either to its conſtant, or to its variable matter, may be ſeparated by heating. In the firſt caſe ariſes *evaporation*; in the laſt, *exhalation*. Both theſe changes often happen together. In both, certain particles of fire are at the ſame time expelled the body. But if it loſes, as for inſtance, a metal heated by rubbing, none of its particles; it cannot certainly be affirmed, that it fills an adjoining body with its igneous particles upon heating it.

§. 131. The igneous particles of a hot body, are always in a certain degree of motion, with which they act on a cold matter, which they are in contact with. The igneous particles of the adjoining cold matter re-act. And hereby the cold matter gains, and the hot body loſes a certain degree of heat. And hence the heat of a body, in contact with a matter, whoſe heat is leſs, gradually diminiſhes, till it and this matter have an equal degree of heat and cold.

§. 132. The greater therefore the number of the acting igneous particles of a body, the greater heat it can communicate. And the greater the number of the reſiſting or counteracting particles of the cold body, the greater the diminution of the heat in the hot body. And therefore in the decreaſe and increaſe of the degrees of heat, we are to conſider the denſity, magnitude, and figure of the hot and cold bodies. Experience therefore eſtabliſhes the following propoſitions, 1. The denſer the cold matter, in contact with a hot body, the ſooner it loſes its heat. And ſo the fluid falls deeper in the thermometer, when ſet in ſnow, mixed with ſal armoniac, than when ſtanding in ſnow only. 2. If two equally denſe, and equally heavy bodies A and B, are in contact with equally cold matters of the ſame ſpecies; and A has a greater, and B a leſs external ſurface, A turns cold ſooner than B. And ſo a meaſure of boiling water, when poured out into a wide and cold veſſel, turns ſooner cold, than when put into a narrower and equally cold veſſel. 3. A ball A remains therefore longer hot, than a body B of another figure, when A and B conſiſt of the ſame matter, and are of equal weight. For, of all ſurfaces, that of a ball or ſphere is the leaſt; the matter they contain being of a like ſpecies and a like weight. 4. If two bodies unequally big, but of the ſame figure, and conſiſting of the ſame matter, and encompaſſed by the ſame and equally cold matters, have an equal degree of heat; the greater continues longer warm than the ſmaller. For, the loſs of their heat is to be eſtimated by the ratio of their external ſurfaces; and the quantity of their heat by the ratio of their maſſes or ſolidities. Heat two lead balls A and B equally intenſe. And ſuppoſe the diameter of A to that of B to be, as 1 to 2. And thus the ſurface of A is to the ſurface of B, as the ſquare 1 to the ſquare 4; and the maſs or ſolidity of A to the ſolidity of B, as the cube 1 to the cube 8. The ball B has eight times as much heat as A. If therefore the ball A turns cold in one hour; B loſes its degree of heat in two hours. For, the greater loſes indeed, four times as much heat as the leſs; but it has alſo eight times as much heat. And thus the times of cooling in equally hot balls of the ſame matter are to each other, as their diameters.

§. 133. If two bodies A and B, of which A is ſuſceptible of more heat than B, are ſo expoſed to an actual fire, that B is nigher thereto, but in contact with A; the fire acts ſtronger on A than on B. And ſo a ball of lead, wrapt up in paper, melts over a flame. A lighted ſmall perfume-candle burns not fully, when ſtanding on ſtone or metal.

CHAP. IV.

Whether Fire be a peculiar Matter.

§. 134. BEFORE the fire, contained in combuſtible bodies, is put into motion, as thereby to kindle them; it appears to be no fluid matter. But if in motion in the combuſtible bodies, as that thereby they burn: We can obſerve either nothing at all, or very little of other matters, diſtinguiſhable from it. Suppoſe for inſtance, you let a lighted ſpirit of wine burn on; one part after another turns to flame, ſo that at laſt not the leaſt trace of it can be obſerved on the bottom of the veſſel. A lighted piece of wood burns ſo, as to leave behind only a few aſhes. And hence ſome philoſophers came to be of the opinion, that fire was no peculiar matter, diſtinguiſhable from the other matters of a combuſtible body. They held, each combuſtible body would turn to fire, on its parts being finely enough reſolved, and put into a quick inteſtine motion. But in oppoſition to this opinion, what follows is to be conſidered. The flame of a combuſtible body may conſiſt of different matters, which together are reſolved into ſo ſmall parts, that there is no diſtinguiſhing them from each other. One among theſe matters may be of ſuch a nature, as beſt and eaſieſt of all to admit of motion and reſolution, either on rubbing the body, or letting a combuſtible body act upon it. This matter, by its motion, may reſolve the other matters of the body in the fineſt or ſubtleſt manner, and remain mixed with the infinitely ſmall reſolved parts. And this matter ſhould thus be conſidered as the proper and pure fire of a body. Deny this matter we cannot; and conſequently hitherto no proof has been adduced to ſhew, that fire is no peculiar matter.

From air and water, fire indiſputably differs. For, air withſtands flame, and preſſes the fire againſt the burning body; and water extinguiſhes the fire of burning and glowing bodies. And conſequently in the fluid matters, that take fire, and are mixed with water, ſomething is contained, that is to be diſtinguiſhed from fire. The experiments of the younger *Geoffrey* have ſhewn, that in a pure, good ſpirit of wine, above half its weight is water. If fixed matters are burnt, there remains at laſt an aſh, that burns not; which is a manifeſt indication that in ſuch combuſtible bodies there is ſomething, which is not fire. In order to maintain that fire in each body is one of its proper peculiar matters; it remains to explain how from one and the ſame matter ſuch innumerable ſpecies of fixed and fluid bodies can ariſe.

PART III.

Of Water.

CHAP. I.

Of the Phænomena of Water.

§. 135. WATER exhibits itſelf to our eyes a fluid and tranſparent matter, adapted to extinguiſh flame. It is called pure, when without either ſmell, taſte or colour, Yet it is never quite free from earthy parts, as always leaving behind, never ſo often diſtilled, ſome earth. And beſides thoſe earthy matters, it is mixed up with air and fire.

1. The air, concealed in water, comes to be diſcovered on removing, by means of the air-pump, the air, incumbent on water in a veſſel. For, we obſerve a number of bubbles ariſing out of the water. If the water is hot, they come forth larger and in greater quantity. Theſe are hollow ſpherules of air, as is evident from another experiment. You may convey ſome air by means of a tube to the bottom of a veſſel, filled with water, out of which a ſingle bubble more refuſed to riſe under the bell of the air-pump. So ſoon as this little air comes out of the tube under the water, it mounts upwards thro' the water in the form of ſuch bubbles, as ariſe out of that water, with which the firſt experiment was made under the bell of the air-pump.

From this the following properties of the air, included in water appear. 1. It has a tendency to eſcape out of the water. 2. This tendency is ſtronger than the weight of the water and the coheſion of its parts. 3. It is elaſtick, §. 51. 4. Its ſpring is heightened by heat. 5. Its ſpring is equal to the preſſure of the external air. 6. Without this preſſure, no air could remain included in water. 7. As each ſpherule of air in water, by its ſpring conſtantly labours to force out of it; ſo each acts on every ſide on the contiguous particles of water, and excites them without intermiſſion to retact. If air ſtands on water, which has been diſcharged of it, it gradually inſinuates into it again. If you fill a glaſs ſphere with water, diſcharged of air, and leave an air bubble upon it, it gradually loſes itſelf, and all of it is at laſt ſwallowed up by the water. If you give the air, over the water, a continued preſſure, it inſinuates not ſo readily but much ſooner communicates itſelf to the water, on ſwinging the ſphere round, in which ſome air ſtands over the water. From this we may draw the following concluſions. 1. As air in its natural ſtate preſſes much ſtronger on the earth's ſurface, than the coheſion of the particles of water reſiſts; ſo the ſpherules of air, of which a maſs incumbent on the water conſiſts, muſt be greater than the inteſtices in the water. 2. But yet as air is more porous than water; this laſt inſinuates into the interſtices of the incumbent and preſſing air. And thus water and air come mutually to mix. 3. As water is heavier than air, by the circular motion it acquires a greater centrifugal force than air. §. 97. By this ſtronger force, with which alſo the water is driven againſt thoſe ſides of the ſphere, in which is the particle of air, this laſt will be thus forced thro' it with greater celerity.

2. The fire in water by its motion, gives water fluidity. For, if the heat be ſo diminiſhed, that the quick-ſilver in *Deliſle*'s thermometer ſubſides under 150, the water turns to ice. Above it was ſhewn, that the heat of boiling water extends no further than till the quickſilver in *Deliſle*'s thermometer riſes from the freezing point 150 degrees only, §. 123. And M. *Muſchenbroeck* has found by means of his pyrometer, that the heat of boiling water admits not being heightened to the pitch, that tin ſhould melt therein, §. 127. But this is to be underſtood only of boiling water in open veſſels, from which the boiling water freely evaporates. But if included in a cloſe veſſel, ſuch as *Papin*'s digeſter, ſo that the ſteam no where eſcapes: It may be made ſo hot, as to ſoften bones and ivory, and reſolve and melt pieces of tin and lead, when hanging at a metal wire in the middle of the water.

§. 136. By the force of fire water reſolves into vapour or ſteam, or diſſipates into parts, ſo fine that by virtue of the force of coheſion, §. 52 ſeq. they come, bulk for bulk, to weigh equal with particles of air. By the motion of fire, which never fully quits the ſteam; they are forced into the air from one degree of height to another, and ſuſtained therein by the force of coheſion.

1. If into a darkned room you admit a ray of the ſun, to paſs thro' aſcending ſteams, and view it thro' a magnifying glaſs, it appears like globules floating in the air. As air can never be fully pumped out of a veſſel; ſo in vacuo ſteam riſes out of the water, under the bell of the air-pump. How ſmall the particles of a ſteam continuing ſtill viſible, may be, appears from the experiments with æolipilæ, or wind and ſteam balls, deſcribed in *Wolfius*'s *Experiments*, P. I. c. 7. *Boyle*, in his treatiſe *de mira Subtilitate efluviorum* relates, he had put into a ſteam-ball an ounce of water, and reſolved it by the heat of glowing coals to ſteam, and he found that it continued its motion above a quarter of an hour in form of a cone, 20 inches long, and an inch broad in baſe. The velocity of this ſteam is ſo great, that a portion of it traverſes a length of 20 inches in a ſecond. A quarter of an hour conſiſts of 900 ſeconds. And thus the ounce of water was turned to 900 cones of the ſaid ſize. This ſteam continues ſtill viſible. A drop of water in a glaſs ſphere, whoſe capacity might hold 14000 ſuch drops, is by the heat of the fire ſpread all over this ſpace in inviſible ſteam. The ſphere has a narrow neck, like the tube of a thermometer. If the neck, after heating, is dipt

in quickſilver; this laſt riſes in the ſphere, when the ſteam turns cold, and again condenſes. As the quickſilver riſes thro' the neck into the ſphere, and fills it up; this is a ſign, that the ſteam, ariſen from the drop of water, has occupied the whole ſpace of the ſphere, and expelled the air out of it. For, ſo long as the ſphere is filled with air, no mercurcy riſes therein. The elaſtick force of the internal air is ſo ſtrong, as the preſſure of the external. A proof, that the parts of water muſt be uncommonly ſmall, the *Florentine* experiments afford, in which water was preſſed thro' metals, thro' which no air poſſibly can. Theſe experiments are deſcribed in the *Tentam Florentina*. P. II. and p. 58—68 illuſtrated by *Muſchenbroeck*, with conſiderable additions.

2. Hot water-ſteam is elaſtick; the greater its heat, the ſtronger its tendency to expand. How ſtrong ſoever the action of gun-powder, when fired, yet the action of ſteam, raiſed from an equal quantity of water by a violent fire, is far ſtronger. Profeſſor *Muſchenbroeck*, in his *Eſſai de Phyſique*, §. 872, deſcribes a machine, whereby the elaſticity of heated water-ſteam may be explored. Steam into which he had reſolved 13 grains of water, ruſhed out of the machine with ſo great a violence, as to have forced up three pounds of water 50 feet high. Whereas 13 grains of gun-powder in a

ſmall mortar-piece could force to this height a ball of lead only 4 ounces and 2 drachms in weight.

§. 137. Water, by cold turned to ice, or to a firm body, occupies a larger ſpace. For, veſſels full of water, are not only expanded by it in freezing, but alſo burſt. A remarkable inſtance to this purpoſe we have in the caſe of artificial cold, or the mixture of ſalt and ſnow, or ſtamped ice; as in the *Tentamina Florentina*, P. I. p. 127—164, a braſs ſphere, which according to *Muſchenbroeck*'s calculation was ſo firm and ſtout, as that a weight of 27,720 *lb.* would be neceſſary to tare the metal aſunder, was crackt in ſeveral places by the force of the ice produced in it.

1. The ſpace, into which water turned to ice, expands, is ſo large, that bulk for bulk, the weight of ice is leſs than that of the fluid water. Hence a piece of ice floats in water, §. 74. The *Florentine* academiſts attempted to calculate the increaſed bulk of frozen water in a two-fold manner. The experiments are related p. 139 and 141. l. c. Firſt, they compared a cylinder of water with the cylinder of ice, produced from it, and found, that the bulk of the firſt was to that of the ſecond, as 8 to 9. Then they took a certain weight of water and let it freeze; after which they filled the ſpace of this

ice with water, and again weighed it. And the weight of the firſt was to that of the ſecond, as 25 to $28\frac{1}{19}$. Now 8 is to 9, as 25 to $28\frac{1}{8}$. So that the ratio of 8 to 9, differs but little from the ratio of 25 to $28\frac{1}{19}$.

2. Ice evaporates. You need only expoſe to the air, ſome pointed and ſharp pieces, and you will ſoon obſerve the points and ſharp angles blunted. If you lay a piece of ice on a ballance, you ſoon find, how in a continued degree of cold it loſes in weight. The more violent the cold, the ſtronger the evaporation of the ice. Of this, M. *Mairan* in his *Diſſertation on ice*, P. II. Sect. 3. c. 10. gives a remarkable experience. In the year 1716, in which for ſome days the cold was as great as that of the ſevere winter, 1709; he at times found, that ice, which had lain in the air and northerly wind, had loſt in 24 hours above a fifth in weight.

3. But tho' ice diminiſhes by evaporation, yet its bulk increaſes with the continuance of the cold. *Huygens* in 1667 hung an iron tube, an inch thick, filled with water and well ſecured, in the cold air. In 12 hours it was crack'd in two places. Suppoſe the cold had had to penetrate an inch of iron and water; it is certain the water would turn to ice in two hours. Yet the tube burſt not till after 12 hours. From this it appears, that the ice, by increaſing the

cold from time to time was more and more expanded. On letting water freeze in wide veſſels, which can abide a part of the force of the ice, the ſurface of the ice will be a little bent and raiſed. *M. Mairan* relates c. 2. l. c. that in theſe circumſtances he tapped below the veſſel with ice, and let the water ſtill remaining run off; but found almoſt every time that the bent ſurface of the ice was ſtill more raiſed. Hence ice on large water-places comes to have in a violent degree of cold, long rents, which cauſe a great crack.

4. Alſo water purged from air, expands in freezing, as the ice ariſing from it, in like manner floats in water. *M. Muſchenbroeck* found this by an experiment made with all imaginable care, which he deſcribes l. c. of the *Experimenta Florentina*, p. 143, 144, 145.

5. As water takes up more room, when turned to ice, ſo iron ſmelted and turned hard expands to a larger ſpace. *M. Reaumur* diſcovered this by peculiar experiments, deſcribed in the memoires of the academy of ſciences for the year 1726. At one time he ſmelted iron in ſmall cylindrical crucibles, till quite full of it. At another, in larger crucibles, and poured it out into ſmaller ones, filling them brim full, and with a knife removed the iron at the rim, in the manner of ſtriking corn with a ſtrikle. Then

the iron turned gradually cold. But at its full pitch of hardneſs it was every time forced up over the rims of the crucibles, and like frozen water had an eminence in the middle. Whereas gold and ſilver ſmelted to bars are always depreſſed a-top. From the expanſion of iron in cooling it comes, that the crucibles, in which it hardens, burſt equally as the pots, in which water has froze, tho' you leave the crucibles to cool amidſt live coals. Moſt moulds conſiſt of two pieces, which the founders ſet in a preſs. Now *M. Reaumur* has often ſeen, that it was with much labour they could turn the preſs ſcrews, when they had caſt iron, in large pieces eſpecially. And hence ſmelted iron moulds better than the other metals. For, as it expands, it ſeeks the ſmalleſt empty places, and takes the impreſſion of the ſmalleſt part of the mould. Letting iron become as fluid as poſſible, and then purging its ſurface of every impurity, and throwing in a piece of hard iron; this laſt will float and ſtand out of it ſome way. If puſhed to the bottom, it again emerges on letting it go. If a piece of hard iron is laid on the bottom of the ſmelting crucible, and ſmelted iron poured thereon, the hard riſes up. And thus hard iron is lighter, and conſequently more expanded than ſmelted iron. This has been found to hold in biſmuth and antimony.

6.

6. Water only takes up more room, when juſt on the point of freezing, and when actually froze; and hence becomes lighter than an equal portion of moderately cold water. Before, when in the ſtate of perfect fluidity, it takes up a narrower ſpace, than when colder. For, if a narrow flask with a long neck be filled to its middle with water; and the flask then expoſed to a greater degree of cold, you obſerve the water at firſt to fall ſome lines deep in the neck. But ſo ſoon as it is to turn to ice, it begins to riſe. The volume which it has in this degree of cold, will be encreaſed about $\frac{1}{26}$ up to the heat of boiling; and conſequently decreaſed by ſo much, when brought from this degree of heat to that of the cold, by which it may turn to ice. The experiment for the purpoſe the abbè *Nollet* deſcribes in his T. IV. *Leç.* XII. §. 1. *Experiment* II. You take a diſtilling-glaſs with a neck 15 inches in length, and 12 or 14 lines in diameter internally. You pitch upon a water-meaſure for the purpoſe, and pour it 25 times into the glaſs, and mark with a thread the place of the neck, at which the filled water of theſe 25 meaſures ſtands. Then you ſtill pour in 1, 2 and 3 meaſures more, marking at each meaſure, where the water ſtands. After this you take out theſe laſt meaſures again, that only 25 meaſures remain in the glaſs. The veſſel ſtands in ſnow or

ſtamped ice. And the water to fill with, in a veſſel by it in this ſnow or ice. The diſtilling cucurbit or body is placed in ſand, which may be heated by glowing coals. In the water of the body a thermometer is hung, on which the degree of the heat of boiling water is marked. If now the ſand is heated, the water riſes up in the neck of the body: And coming at length to boil, and its heat to be ſo great, as is poſſible in a water that evaporates freely; you find the water riſe up to the mark 26, at which before the cold water ſtood, after putting 26 meaſures into the body. You heighten the fire. But neither the water in the neck of the body, nor the fluid matter in the thermometer riſes any higher.

CHAP. II.

Of the Nature of WATER.

§. 138. THE leaſt parts of water have a peculiar degree of firmneſs and hardneſs, which may be perceived partly from the hardneſs of ice, partly from the re-action, with which water reſiſts the violence of firm bodies. A board floating on water, may be juſt as eaſily cut, as when lying on a hard block. If a leaden bullet is ſhot obliquely on a ſurface of water; it will be flatted. As *M. Carree* found by repeated trials, as related in the memoires of the *Academy of Sciences* for the year 1705. If the angle under which the bullet is ſhot into the water, is only of a few degrees, the bullet ſprings on the other ſide out of the water again. For, the more oblique the ball goes into the water, the more parts of water reſiſt it. If a ſmall, flat and ſmooth ſtone be thrown very oblique on a ſurface of water, it ſprings ſucceſſively out of and into the water, and in this manner continues its way in and above the water. *M. Kruger* in his *Natural Philoſophy*, §. 81. relates, he had found, that a ball which he had ſhot out of a rifled barrel againſt a broad lake, had ſprung up three times ſucceſſively. In like manner in ſea-fights many cannon balls are reflected from the water.

§. 139. The fixed and hard parts of water would therefore, like the parts of metals, conſtantly form a hard and firm body, were they not ſeparated aſunder by fire. The fire between them is the fluid matter, in which they float. Now the query is, how it happens, that on the receſs of the fire, when they conſtitute a firm body, they expand into a greater ſpace.

1. We are not to look for the cauſe in the expanſive force of the air. For, even water void

of air, takes up a greater ſpace when froze, §. 137. n. 4.

2. As in the cold winter of 1740, I read publick lectures on the degrees and cauſes of cold; I fell on the thought, that the particles of water which are commonly held to be round, were in the freezing poſſibly divided; whence either ſmaller globules or angular corpuſcles aroſe. In both caſes, the matter before fluid, would now occupy a larger ſpace. A leaden bullet of half an ounce is an inſtance, which may be turned either to ſmall globules or angular parts. This opinion I afterwards propounded in 1742 in my *Inſtitutiones Philoſophiæ Univerſæ*, P. I. §. 1350, 1351. For ſuch a change to happen, a force muſt lie either in the particles of water, whereby they are divided; or in the cold, a certain matter muſt force into the water, which produced ſuch a change. Such a matter profeſſor *Muſchenbroeck* in his *Inſtitutiones Phyſicæ*, §. 948, *ſeq.* ſuppoſes: But he affirms not, that this matter cauſes ſuch a change in the conſtituent particles of water; maintaining only thus much, that it ſeparated the particles of water aſunder, and produced as it were, a degree of fermentation among them. Among the grounds or reaſons, that ſeem to eſtabliſh the reality of ſuch a matter, that effect is obſervable, which is produced by ſpirit of nitre in ice. If poured into water,

whoſe heat in *Fahrenheit*'s thermometer ſhews 33 degrees; the heat of the water is heightened in ſuch a manner, as that the ſpirit of wine or quickſilver in the thermometer riſes up to 41. But ſpirit of nitre poured on grated ice, there ariſes an extraordinary degree of cold therein. Are we not therefore to ſuppoſe ſomething in ice, *Muſchenbroeck* demands, §. 956, differing from water, and admitting the being expanded and heightened by the ſpirit of nitre? But poſſibly the conſtituent parts of water may be of ſuch a nature, as to unite into hollow and elaſtic globules, when in mutual contact. A ſimilar diſpoſition appears in air; ſo long as its minute parts lie concealed in water, their elaſticity is unobſervable. But ſuffered to riſe out of the interſtices of the water, by diminiſhing the external air, as that ſome of them come in mutual contact, they form veſicles or bubbles, that burſt by their elaſticity. The aſcending ſteam of water the magnifying glaſs has already diſcovered, to conſiſt of hollow globules, §. 136. So that the elaſtick force of ice is thus to be ſought for in the conſtituent parts of frozen water. This conjecture I treated on in 1753 in a programma, entitled, *Unde vim elaſticam adipiſcatur aqua rareſcens.*

3. *M. Mairan* in his treatiſe on ice, P. II. §. 1. c. 7, 8, and 9. aſcribes to the conſtituent

parts of water a force, whereby they have a tendency to unite under an acute angle. In favour of this conatus he adduces two phænomena. The firſt threads or filaments of ice, that ariſe on the ſurface of the water in a veſſel, have different inclinations to the ſides of the veſſel, and form therewith different angles, which are generally of 60 degrees. On theſe firſt threads the ſecond place themſelves under different angles; and on the ſecond others again ſettle, and ſo on, till an entire web and film of ice is formed. Falling ſnow oftner conſiſts of ſtars, put together of 6 equal rays, and ſtanding aſunder at equal diſtances. And thus we have ſmall filaments of water or ice floating in the air, where they have full liberty to exert their conatus, to unite together under an angle of 60 degrees. For, this number is the ſixth part of the 360 degrees of the circumference of a circle, and conſequently, the meaſure of each of the 6 equal angles, which with their points unite in its centre.

4. Water, in order to turn to ice, muſt have its parts come in mutual contact. For, if ſalts are mixed with water, they render it ſo cold, that the quickſilver in a thermometer, hung therein, falls below the freezing point: But then they prevent the water from freezing. Its conſtituent parts are forced aſunder by the pointed

parts of the ſalts. The experience, from which we learn, that ſalts diſpatch the ſmelting of iron, affords a proof in this caſe. *M. Mairan* in P. II. Sect. 5. c. 1. l. c. confirms the thing by an experiment. In 1716 he took four pieces of the ſame ice, in bulk and figure almoſt mutually equal. Each was about a cubic inch big. After letting them dry well in a great degree of cold, he ſtrewed one with dry, and finely rubbed table ſalt ſo as to be quite covered therewith, as if candied or cruſted over; the ſecond in like manner with ſaltpetre, and the third with ſal-armoniack. In order to prevent any degree of heat coming to them in ſtrewing the ſalts, the ſalts ſtood in the very ſame degree of cold of the air, that the pieces of ice did. *M. Mairan* alſo made uſe of a piece of ice inſtead of a ſcoop, with which he ſhot the ſalt on the three pieces of ice, laying hold on the ſcoop of ice with a cold iron forceps. He directly found, that the points and angles of this ſcoop of ice were melted down, on taking up the ſalts therewith, and ſtrewing them on the pieces of ice. The three ſtrewed pieces of ice, along with the fourth unſtrewed, he conveyed on a net of yarn in a room, in which he maintained the air in the degree of heat of the obſervatory at *Paris*, that is, to the 10th degree of *Reaumur*'s thermometer. This experiment he repeated three ſeveral times. The piece cruſted or coated over with common ſalt was always melted down in leſs than an hour, the piece with ſal-armoniac within five or ſix minutes after; and that with ſaltpetre took almoſt two hours to diſſolve in; the uncruſted piece of ice above 5½ hours.

5. As the ſalts force aſunder the parts of ice and water, and mix therewith; not only the quantity of the matters, but the number of the ſurfaces is encreaſed into which the fire of adjoining bodies may inſinuate, §. 132. And ſo this is the reaſon why water, ſnow and ice turn colder by ſalts, of no greater a degree of coldneſs than ſalt, ſnow and ice themſelves. And hence ſpirit of wine heightens the degree of cold of the freezing matters, when poured thereon. For, it diſſolves them into ſtill ſmaller parts, into which new ways are made for the fire. From this very reaſon, the degree of cold of the freezing matters happens with greater diſpatch, on ſetting the veſſel with them on glowing coals. If a vial full of water ſtands in theſe freezing matters, the water is turned to ice, ſo the freezing matters diſſolve.

CHAP. III.

Of the Effects of WATER.

§. 140. IF water inſinuates into earth, wood, and other ſpungy bodies, they diſcover a ſtrong degree of expanſion. Hempen ropes turn thicker and ſhorter, ſo as to heave or raiſe appended weights. If earth well dried, and turned to duſt, is preſſed firm together in a veſſel, and water poured thereon, the earth heaves or ſwells ſo, that ſometimes the veſſel burſts. Which alſo happens, on filling a veſſel with dry beans and peaſe, and pouring water on them, and cloſing up the veſſel. In mill-ſtone quarries it is uſual to make ſmall holes cloſe to each other quite round, about two inches deep, and between three and four lines in diameter wide. Into theſe are driven with great violence plugs of willow-wood, that have been well dried in the oven, and water poured on them. By which the plugs ſwell in ſuch a manner, that a piece of the rock looſens. As in all theſe bodies there are interſtices innumerable and highly ſmall, the inſinuating water is ſo ſubtilly divided, as when reſolved into ſteam. Were we therefore ſure, that wood, and earth, and the other ſpungy bodies did not themſelves contain a certain elaſtic matter, which was put into motion by the inſinuating aqueous particles; from the ſwelling ariſing in theſe things by the inſinuating water, a proof might be drawn, that water acted with an elaſtic force, if brought to a ſtate, as to be reſolved into a ſteam.

But it may well be, that earth and the other ſpungy bodies contain an elaſtic matter, which begins to act by means of the inſinuating aqueous particles. *M. Reaumur* from many trials, which he made on the nature of earth, and on the characters of the ſeveral ſpecies thereof, and deſcribed in the memoires of the Academy of Sciences for the year 1730, has diſcovered in earth a peculiar odour, inſeparable from it. He moiſtened a number of times a day ſmall cakes of earth for fourteen days together, and again every time left them to dry: But in the laſt experiment he found them ſmell no leſs than in the firſt. But as earth ſmells not unleſs when moiſtened; it ſeems to him, one might conclude, the matter forming the odour of earth, to be too ponderous, to be raiſed barely by the warmth of the air; and thus it became neceſſary for water to reſolve it, and carry along with it the odour. Poſſibly, ſays he, water cannot convey the odour far, and conſequently, the ſphere of the odour of earth is inconſiderable. When water penetrates the grains of earth, it cauſes therein ſome alteration. And the air-bubbles then burſting forth give ſuſpicion of a preceding fermentation therein. Were this rightly proved, ſays he at laſt, we ſhould have a very probable reaſon for the augmentation of the volume of each grain of earth, on being penetrated by water.

§. 141. Water damps the violence of fire in burning and glowing bodies, when poured in a ſufficient quantity thereon. This effect ariſes from water holding little fire in it, and conſiſting of perfectly firm and hard parts. If therefore a ſufficient quantity of them comes on a burning or glowing body; the parts of the excited fire part aſunder, and acquire an unſurmountable reſiſtance.

§. 142. If pure ſmelted gold, or pure ſmelted ſilver is poured into cold water: Both of them paſs through it without any violent noiſe, and become divided into grains. This we call *granulation.* Whereas ſmelted iron, tin and lead, cauſe a violent and dangerous commotion in cold water. And if ſmelted copper is poured therein, a violent exploſion ariſes, and water and copper are thrown about not without the greateſt danger. The moſt violent and moſt dangerous motion of all ariſes on pouring a little water only on ſmelted copper, or iron or other ore. Exploſion and diſcharge are ſo violent, as in nothing to come ſhort of the effects of gunpowder. The reaſon may be partly in the elaſticity of the aqueous particles, and poſſibly, chiefly in the elaſticity, concealed in the particles of the metal.

§. 143. The force with which water diſſolves certain bodies, is principally to be aſcribed to the fire; as *M. Eller* has ſhewn from the following experiments, contained in his *Diſſertation ſur la Nature, & les proprietés de l'eau commune conſiderée comme un diſſolvant*, inſerted in the memoires of the *Berlin* academy of ſciences, T. VI. p. 77, 78. Eight ounces of pure water, whoſe heat in *Fahrenheit*'s thermometer indicates the 33d degree, ſcarce diſſolve the 64th of their weight of common ſalt. Then on taking from the water this degree of heat, ſo as to turn to ice, the little ſalt diſſolved ſinks to the bottom. Whereas on heightening the heat of the water to the 12th degree of *Fahrenheit*'s thermometer; two ounces of ſalt will be diſſolved in eight of water. And if the heat of the water is raiſed to boiling, it diſſolves almoſt its own weight. If the water be ſuffered gradually to remit from the heat of boiling down to the leaſt degree, when ready to turn to ice; you at laſt find the whole quantity of diſſolved ſalt at the bottom of the veſſel. From this it is very evident,

dent, that water diſſolves ſalts and other bodies by means of its fire.

PART IV.

Of LIGHT.

CHAP. I.

Of the general Properties of LIGHT.

§. 144. BY light we underſtand a fluid and inviſible matter, by whoſe motion bodies become viſible. Sometimes alſo by light we mean this motion only.

It is propagated from its ſource in right lines, which are called rays of light. The rays Cm, Cn, Co, Cd, fig. 9. Plate II. which flow from a point C, are diverging, or continue removing ever farther aſunder, the farther they move on from the radiant point.

But if the breadth of an enlightened ſurface IK, fig. 12. Plate II. to the diſtance of the radiant point IH, or KH, is, as 1 to 2000000: It is the ſame thing, as if the rays HI and HK fell parallel on the ſurface. For, in that ſuppoſition the angle at H is ſo ſmall, that the angles at I and K differ little from right angles. And conſequently the rays HI and HK may be conſidered as perpendicular lines, drawn from H on the line IK at I and K. Such lines run parallel, or ever remain equidiſtant aſunder. When IK is to IH or HK as 1 to 2000000, the angle at H is about a ſecond. But the angles alſo at I and K would by the eye be undiſtinguiſhable from two right angles, ſuppoſing the angle at H to be half a minute. And then by the greater canon of ſines in trigonometry IK would be to KH, as 1454 to 1000000; that is, as 1 to 6877. Suppoſing the breadth of the ſurface IK to be two lines, in that caſe IH is equal to 13754 lines. For, 1 : 6877 : : 2 : 13754. And thus a point, from which the light falls on a breadth of two lines, being 140 feet diſtant therefrom, the rays of light appear to ſtand parallel thereon.

§. 145. The diverging rays of a luminous point exhibit either a ſphere or a cone. In both caſes the denſity of the light decreaſes, as the ſquare of the diſtance from the luminous point encreaſes, when the rays extend thro' a ſpace, in which they are not reſtrained by any interpoſing matter.

A ſphere, formed by the diverging rays of a luminous body, may be divided into ſpheres of different magnitudes, having the luminous point for their common centre. The larger theſe ſpheres, the leſs the denſity of the light on their ſurfaces; as the diſtances between the diverging rays encreaſe with the encreaſing diſtance. And thus the denſity of the light on the ſurface of a ſmall ſphere, to the denſity of the light on the ſurface of a larger, having a common centre with the leſs, is as the ſurface of the greater to that of the leſs. Suppoſe the ſurface of the greater to that of the leſs, to be as 4 to 1. And thus the denſity of the light on the ſurface of the leſs, to the denſity of the light on that of the greater, is as 4 to 1. Inſtead of whole ſpherical ſurfaces take their halves, as the half ſurface of a leſs ſphere to that of a greater, is as the whole ſurface of the leſs to the whole ſurface of the greater, fig. 15. Plate II. The leſs hemiſphere may be deſcribed by the ſemicircle FCG, and the greater by the ſemicircle DBE. The ſurfaces of theſe hemiſpheres are to each other, as the ſaid ſemicircles. So that the denſity of the light on the ſurface of the leſs hemiſphere to the denſity of the light on the ſurface of the greater, is as the greater ſemicircle DBE to the leſs FCG. But by geometry DBE is to FCG, as the ſquare of the diſtance, or ſemidiameter AB, to the ſquare of the diſtance, or ſemidiameter AC. And thus the denſity of the light on the ſurface of the leſs ſphere in C, to the denſity of the light on the ſurface of the greater in B, is as the ſquare of the greater diſtance AB, to the ſquare of the leſs AC. If therefore AB is = 2 AC, the denſity in C to the denſity in B, is as 4 to 1; and thus the denſity decreaſes, as the ſquare of the diſtance encreaſes.

If the diverging rays of a luminous point D fig. 16. Plate II. form a cone: The baſes of a leſs and greater cone, having the luminous point for their common vertex, are circles. But in both circles the number of rays is equal. But in the leſs they lye cloſer together than in the greater. So that the denſity of the light in the leſs circle EF, to the denſity of the light, in the greater AB, is inverſely as the greater circle AB, to the leſs EF. But the circle AB to the circle EF, is as the ſquare of the radius CB, to the ſquare of the radius GF. And thus the denſity of the light in the leſs circle EF to the denſity of the light in the greater AB, is as the ſquare CB to the ſquare GF. As CB is parallel with GF, CB is to GF as DC to DG. Conſequently the ſquare CB to the ſquare GF, is as the ſquare DC to the ſquare DG. And therefore the denſity of the light in G, to the denſity of the light in C, is as the ſquare DC to the ſquare DG. Suppoſe DC = 2 DG. And thus the denſity in G to the denſity in C, is as 4 to 1; and the denſity in C to that in G, as 1 to 4. So that the denſity of the light in C decreaſes, as the ſquare of the diſtance CD encreaſes.

If therefore the rays of light AD and BD, fig. 16. Plate II. are converging, and unite in a point D; their denſity encreaſes, as the ſquare of the diſtance decreaſes.

§. 146. In the denſity of the rays the power or intenſity of the light conſiſts. And thus if light diffuſes itſelf in diverging rays, reſtrained by no interpoſing matter; the intenſeneſs of the light at the farther diſtance, to the intenſity at the nigher, is as the ſquare of the nigher diſtance to the ſquare of the farther diſtance.

§. 147. No one ray of light impedes the other in its action, fig. 13. Plate II. For, if for inſtance, rays fall from three luminous bodies A, B, C, through a narrow hole upon a wall in a dark room; each luminous body will be pictured or repreſented apart thereon, as in *a*, *b*, *c*. And fig. 14. Plate II. if rays of light fall from a ſingle body B through a number of ſmall holes upon a wall in a dark room; the ſingle body appears as many times thereon, as there are holes: as ſuppoſe the holes are in *b*, *b*, *b*.

§. 148. And in this manner, according to *Muſchenbroeck* in his *Inſtitutiones Phyſicæ*, §. 1070, ve may diſcover, how infinitely fine or ſubtle he rays of light muſt needs be. If you lay yourſelf on your back, and cover one eye with a paper, through which a hole is made, whoſe ſpace admits twenty hairs of the head; through this hole you may ſurvey half the heavens; which is ſo extenſive, as to be capable of containing 1000, 000, 000, 000, 000 fixt ſtars. Suppoſing there come from a ſingle one 100 rays of light only into the ſaid opening or hole, a hundred thouſand billions of rays of light would preſs through it into the eye. Divide 100 by 20. And thus a ray of light would be five thouſand billions of times finer than a hair of one's head.

§. 149. If the aperture is leſs than the luminous body ABC, fig. 13. Plate II. it would be reverſed on the wall, as *cba*. For tho' rays are emitted from each point thereof in right lines; yet on account of the narrowneſs of the hole, only thoſe, which proceed from the upper parts obliquely down, and from the under parts obliquely up, can force through the aperture.

CHAP. II.

Of the Reflection of the Rays of LIGHT.

§. 150. A Smooth and opaque ſurface of a body, whether plain and even, or bent, is called a *mirrour* or *ſpeculum*. If a ray of the ſun falls in a right line FE, fig. 17. Plate II. on a plain mirrour AB, it will be reflected from E to ED in ſuch a manner, as that the angle of reflection DEB is equal to the angle of incidence FEA. Experience itſelf teaches this, when the mirrour is a portion of a ſphere, and either convex as *ab*, or concave as $\alpha\beta$. If the ray falls in the perpendicular CE on this mirrour, it is reflected back on itſelf.

§. 151. The perpendicular line CE, fig. 17. Plate II. to the mirrour in the point E, in which the ray falls from F, and from which it is reflected to D, is called the *cathetus of obliquation*, and forms equal angles with the incident ray FE, and the reflected ED, be the *ſpeculum* either plain, concave or convex. If the mirrour AEB is flat, the perpendicular line CE forms with EA and EB the right angles $o + y$ and $x + u$, which are mutually equal. The angle of incidence o, which is made by the incident ray FE with EA, is in like manner equal to the angle of reflection x, which the reflected ray ED makes with EB, §. 150. And deducting equal quantities from equal quantities, as o from $o+y$, and x from $x+u$, there remain equal quantities y and u.

The incidence and reflection happen in the point E, which remains the ſame, be the ſurface ſtraight or bent. The reflection on the concave ſpeculum αEβ, and the convex aEb, happens therefore in the very ſame manner as on the plain AEB. So that alſo the angle y is equal to the angle u on the convex and concave mirrours.

§. 152. The centre C, fig. 17. Plate II. of a ſphere, of which a ſpherical ſpeculum is a ſegment, is called the centre of the ſpherical ſpeculum. Thro' this the cathetus of obliquation always paſſes on a ſpherical ſpeculum CE: As each line, perpendicular to the periphery of a circle, muſt paſs through its centre.

§. 153. The diameter of a ſphere ACB, fig. 1. Plate III. of which a concave ſpeculum IBE is a ſegment, is called the diameter of the concave ſpeculum; and in ſo far as it paſſes through the middle of its arch at B, its axis. The chord which may be drawn from I the one extremity of the greateſt arch of the ſpeculum to E the

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other extremity, is called the *breadth of the concave mirrour.*

§. 154. If a ray of the ſun DE, fig. 1. Plate III. which falls on a concave ſpeculum parallel to its axis, §. 144. forms with the cathetus of obliquation CE an angle *m* of 60 Degrees; the reflected ray falls on the ſurface of the ſpeculum, and unites itſelf at B with its axis. For, as the parallel lines AB and DE are interſected by the right line CE, the alternate angles *p* and *m* are mutually equal. And thus if $p = 60$ Degrees. As *n* is equal to *m*, §. 151; ſo alſo $n = 60°$. If the ſum of two angles in a triangle makes 120°, the third angle is 60°. So that in the triangle BCE the angle $u = 60°$. A triangle, in which each angle is 60°, is equilateral. So that BE = BC, the radius; and muſt therefore, as the ſide of a hexagon, fall on the point of the periphery B, in which CB terminates.

§. 155. But if the incident ray KG, fig. 1. Plate III. forms with the cathetus of obliquation GC an angle *o*, which is under 60 degrees; the reflected ray GF joins with the axis AB in the point F, diſtant from the ſurface of the ſpeculum leſs than about a fourth of a diameter of the ſpeculum. For, not only the angle *x*, §. 151. but alſo the angle *y*, as an alternate angle, is equal to the angle *o*. So that in the triangle GCF and the angles *x* and *y* at the baſe are mutually equal, and conſequently alſo, the legs CF and GF. Now as the angle *o* is under 60 degrees; ſo alſo as well the angle *y* as *x* is under 60 degrees. And therefore the angle *a* is greater than *y* and *x* ſeparately. To the greateſt angle in a triangle ſtands oppoſed the greateſt ſide. And thus GC is greater than the reflected ray GF. So that GF cannot unite with the axis AB at the point B on the ſurface of the ſpeculum. For, that can only happen, when the reflected ray is equal to the cathetus of obliquation, §. 154.

But the diſtance FB, which the point F has from the ſurface of the ſpeculum at B, is leſs than a fourth of the diameter, or than the half of the radius. For, as in each triangle the ſum of two ſides is greater than a ſingle ſide; ſo is CF + GF greater than the radius GC; and conſequently alſo, greater than the radius CB, as being equal to the other. If you ſubſtract from a greater and leſs quantity two equal quantities; the greater leaves a greater; and the leſs, a leſs remainder behind.

Now if CF + GF is greater than FB + CF
and GF is equal to CF.
CF is greater than FB.

And therefore FB is ſtill ſhort of a fourth o the diameter, or a half of the radius of the concave ſpeculum.

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§. 156. When thus the rays of the ſun fall on the ſurface of a concave ſpeculum, parallel with its axis, and with the cathetus of obliquation make an angle under 60°; they will be reflected and united into a ſmall ſpace before the ſurface, at a diſtance, leſs than a fourth of its diameter; and thus come together denſer therein, than they are on the concave ſurface. The rays of the ſun collected in this ſpace have the power of heating, ſetting on fire and melting. And hence this ſpace is called the burning-point or focus; and the concave ſpeculum, a burning-mirrour. The effects of the large burning-mirrours, executed by *Tſchirnhauſen* are deſcribed in the *Acta Eruditorum*, for the month of *January* 1687.

§. 157. The leſs the angle *o*, fig. 1. Plate III. which the incident rays KG make with the cathetus of obliquation GC, the cloſer the reflected rays GF run together in the focus. The angle *o* is equal to the angle *y*. This laſt is meaſured by the arch GB. If GB is taken double, you have the arch of the whole breadth of the concave mirrour. And hence in that caſe we are to conſider the number of degrees of its arch. Suppoſing the angle *o* or *y* = 15 degrees, the arch of the breadth has 30 degrees. In a concave mirrour of a ſmall ſphere a greater breadth than this, contributes nothing conſiderable to the intenſeneſs of the rays. If the burning mirrour is of a larger ſphere, the arch of the breadth need be only 18 degrees at moſt, and conſequently the angle *o* or *y* 9 degrees only. For, the greater the ſphere, the greater is a degree in the arch of the breadth. Suppoſing 15 degrees in the arch of a greater burning-mirrour to extend through as great a curvity, as 30 degrees in the arch of a leſs burning-mirrour; the reflected rays run together equally cloſe in both foci. And if thus the breadth of this greater burning mirrour had in like manner an arch of 30 degrees; all the rays, which ſhould run from off the concave ſurface from the 30th to the 15th degree into the focus, would be more diſtant aſunder, than the rays in the focus of the leſs burning mirrour, whoſe breadth was an arch of 30 degrees. Conſequently they would not act in the focus much ſtronger than the rays in the focus of the leſs ſpeculum.

§. 158. As the rays come therefore always denſer together in the focus, the leſs the angle *o* or *y*; ſo the focus, in which the rays are denſer together, is further diſtant from the concave ſurface than the focus, in which the rays have a leſs degree of denſity. But the diſtance of the focus F, fig. 1. Plate III. will be never equal to half the radius, §. 155. The point, where the radius BC is biſſected, call *o*. The denſer therefore the rays in the focus F, the nearer they are to the point *o*, and the leſs the line between *o* and F. The leſs this line, the greater number of times it is contained in half the radius. In order, therefore, to know how the denſity of the rays decreaſes, ſo the breadth of the arch encreaſes with the number of its degrees, in the caſe of having burning mirrours of equal diameters or ſpheres; the ratio of the line *o*F to half the radius BC muſt be made out by calculation. How to perform this, baron *Wolfius* ſhews in his *Elementa Catoptricæ*, §. 211. As ſuppoſe the breadth of the arch of the concave ſpeculum to be 6 degrees; *o*F is to half the radius, or to the radius BC, as 1 to 1457. If the breadth of the mirrour is 30 degrees; *o*F is to the radius of the mirrour, as 1 to 56.

§. 159. But if one burning mirrour is of a greater ſphere than another; its focus has a greater degree of power or intenſeneſs, than the focus of that other, when the arches of their breadth are mutually equal in number of degrees. For, the concave ſurface of the mirrour of the greater ſphere intercepts a greater number of rays, than the concave ſurface of the mirrour of the leſs ſphere.

§. 160. As the focus of a concave ſpeculum falls between the fourth and fifth part of its diameter, §. 155; the diſtance of the focus from the concave ſurface is the greater, the greater the diameter of the burning mirrour. As ſuppoſe a burning ſpeculum to be an ell in diameter; and another 4 ells; the focus of the firſt falls almoſt a quarter of an ell, and of the ſecond almoſt an ell diſtant from the concave ſurface. The *Roman* fleet in the days of *Archimedes*, lay at leaſt 30 paces diſtant from the walls of *Syracuſe*. Should *Archimedes* therefore have ſet the ſhips on fire with a ſpherical burning mirrour, its diameter muſt have been upwards of 120 paces.

§. 161. The rays which fall on a ſpherical convex ſpeculum HI, fig. 2. Plate III. in ſuch a manner, as that they run parallel with its axis BC, become diverging by the reflection. The ray AB returns on itſelf, §. 150. The cathetus of obliquation EF, drawn to the point, on which the parallel ray DE falls on the ſpeculum, makes with the radius EC of the ſpeculum a right line. The radius EC, and the axis BC are diverging. And therefore alſo the cathetus of obliquation EF, and the incident ray DE parallel with the axis, are diverging. The cathetus of obliquation forms equal angles between the incident ray DE and the reflected EG, §. 151. And therefore the reflected muſt be diverging from the parallel incident ray.

§. 162. A ſpherical convex ſpeculum reflects therefore the incident rays parallel with its axis in ſuch a manner, as after the reflection to act with a much weaker force.

§. 163. A plain ſpeculum reflects parallel the parallel incident rays. Theſe reflected rays gain therefore no greater force, than they had in the incidence.

CHAP. III.

Of the Refraction of the Rays of LIGHT.

§. 164. WHEN a ray of light paſſes out of one medium into another, and in that other medium proceeds in a line, which makes an angle with the former; this change of direction is called its *refraction*. But both ſpaces or mediums muſt differ in denſity, fig. 1. Plate IV. Suppoſe the medium ABCD to be glaſs, and the medium round the glaſs to be air. Draw at F the perpendicular EFG, and at K the perpendicular HKI. If a ray of light NF falls obliquely on AB, it proceeds not along NFL, but breaks itſelf in the glaſs, and inclines towards the perpendicular FG, and goes on unvaried to the limits of the glaſs K. But in the iſſuing out at K it proceeds not to P, but turns or declines from the perpendicular KI, and takes the line KO. If a ray falls perpendicular it goes on unbroken, or unrefracted through the medium into which it enters.

§. 165. The angle which the ray NL incident on and propagated through the glaſs, and the broken or refracted FG forms at F in the glaſs, is called the *angle of refraction:* The angle which the refracted ray FK makes with the perpendicular FG, or the *axis of refraction*, at F in the glaſs, the *refracted angle:* And the angle, which the incident ray NF forms with the perpendicular EF, or the *axis of incidence* at F, the *angle of inclination.*

§. 166. Deſcribe with the perpendicular AC an arch AD; and with the perpendicular CG, an arch GE, fig. 3. Plate III. The angle of inclination DCA, which the ray DC, incident out of air into glaſs, forms with the perpendicular AC, is equal to the vertical angle ECG, on producing the perpendicnlar, and the incident ray through the ſpace or medium RM. CF is the refracted ray, and conſequently the angle FCG the refracted angle. The perpendicular line HE, drawn from the point E, where the arch GE interſects the line EC, to CG; as alſo the perpendicular line D*o*, drawn from the point, where the arch AD interſects the line DC, to AC, is the ſine of the angle of inclination ACD; and the perpendicular line IK, drawn from the point I, where the arch G I interſects the refracted ray C F, to G C, the ſine of the refracted angle F C G. The ſine of the angle of inclination is in a conſtant ratio to the ſine of the refracted angle, as 3 to 2 nearly; when the refraction happens out of air into glaſs: And conſtantly almoſt as 4 to 3, when the ray is refracted out of air into rain-water. And having therefore by obſervation an angle of inclination, and found the refracted angle anſwering thereto; the other refracted angles according to any angle of inclination may be found by calculation: As *Zahn* in his *Oculus Artificialis*, has calculated, and reduced to a table all refracted angles, when the rays are refracted out of air into glaſs, as alſo the angles of refraction according to any angle of inclination throughout the quadrant of a circle. You find the angle of refraction, ſo you deduct the refracted angle from the angle of inclination. For this laſt is the ſum of the refracted angle, and the angle of refraction. As if the angle of inclination is 30 degrees, and the refracted angle 19 degrees, 29 minutes, and 29 ſeconds; the angle of refraction is 10° 30′ 31″.

§. 167. If therefore the angle of inclination of a ray, falling out of air into glaſs, is under 30 degrees; the angle of refraction E C F, fig. 3. Plate III. is $\frac{1}{3}$ nearly of the angle E C G, and conſequently of the angle of inclination ACD. The experiment, whereby *Kepler* diſcovered this propoſition, and the *inſtrumentum anaclaſticum*, deviſed by *Hawkſbee*, by which the refraction may be obſerved in different fluids, baron *Wolfius* deſcribes in his *Experiments*, P. II. §. 153. *ſeq.*

§. 168. If we conſider the refracted ray IC in glaſs, as a ray which goes out of glaſs into air to D; it is ſo refracted, as juſt to fall in the line CD, in which it was incident from air into glaſs. So that ICG is the angle of inclination, which the ray IC in glaſs forms with the perpendicular CG; and ACD the refracted angle, which the refracted ray CD out of glaſs into air forms with the perpendicular AC. And thus the perpendicular IK is the ſine of the angle of inclination, to which the perpendicular *n*B, on account of the equal vertical angle at C, is equal. On the contrary, the perpendicular *o*D is the ſine of the refracted angle. The perpendicular EH is equal to the perpendicular *o*D, as the angles at C are vertical. The ſine of the angle of inclination is to the ſine of the refracted angle conſtantly as 2 to 3, when the ray is refracted out of glaſs into air.

§. 169. As the angle ECF $= \frac{1}{3}$ of the angle ECG; ſo is the angle FCG $= \frac{2}{3}$ of ECG. So that the angle ECF $= \frac{1}{2}$ FCG. The angle of re-

refraction BCD is equal to the angle ECF, as being two vertical angles. If therefore the angle of inclination, which a ray in glaſs forms with the perpendicular, is under 30 degrees; the angle of refraction, which the refracted ray out of glaſs into air forms with the produced ray, half the angle of inclination.

§. 170. A glaſs, which is a portion of a ſpherical ſurface, is called a *Leus*, whoſe ſize is eſtimated by the diameter of the ſphere, of whoſe ſurface it is a portion. And thus a glaſs or lens of 3 feet is a portion of a ſpherical ſurface 3 feet in diameter.

§. 171. Theſe glaſſes or lenſes are divided into convex and concave. The convex are either convex on one ſide only, and on the other ſide plain, fig. 2. Plate IV; or convex on both ſides, fig. 4. The concave are in like manner either concave on one ſide only, and plain on the other, fig. 5. or concave on both ſides, fig. 6.

§. 172. The right line, which goes through the middle of a lens, and through the centre of the ſphere, of whoſe ſurface it is a part, is called the *axis of the lens*; as CBF, fig. 2. CKE, fig. 4. CHA, fig. 5. IK, fig. 6. The centre C of the ſphere, from which the lens is taken, is alſo called the *centre of the lens*. The right line, drawn from it to the point, where a refracted ray falls in or out, is called a perpendicular, as CIK, fig. 2.

§. 173. A ray of light, falling on a curve ſurface, is in the ſame manner refracted in it, as if fallen on a plain ſurface, in contact with the curve in the point of incidence. For, the ray is refracted in an infinitely ſmall part, §. 148. which both ſurfaces have mutually in common.

§. 174. A ray of light, falling on the axis of a lens, ſtands like it perpendicular on the lens, and goes therefore unrefracted through, §. 164. The other rays of light, running on the curve ſurface of the lens parallel with its axis, form an oblique angle with the perpendicular, as HI with KI, fig. 2.

§. 175. As the glaſs of a lens has the ſame denſity throughout, the rays refracted therein go out in right lines, §. 164.

§. 176. If a ray of light GL is incident on the plain ſurface of a convex lens DBI parallel with its axis CBF, and ſo near it, that the angle of inclination GIC or HIK makes not 30 degrees; it will unite therewith behind the lens at the diſtance of its diameter, fig. 2. Plate IV. As the ray GH falling perpendicular on the plain ſurface, it proceeds unrefracted on to the exit at I. Were the ſurface there plain, it would proceed ſtraight on along IH. But on account of the curve ſurface it is refracted. And as this happens in the exit, it is refracted from the perpendicular CIK to the axis CBF. The angle of refraction FIH is = $\frac{1}{2}$ the angle of inclination HIK, §. 169. The parallel lines GIH and ACF are interſected by the perpendicular CIK. And thus the external angle HIK is equal to the internal FCI, and the angle FIH to the alternate angle IFC. And therefore in the triangle FCI the angle FCI is to the angle IFC, as 2 to 1. If the angles are not too great, we may without any conſiderable error aſſume, the ſides to be to each other as the oppoſite angles. Conſequently, the line FI = 2 CI. But CI is the radius of the lens. And therefore the diſtance FI is equal to its whole diameter. As FI is very near the axis FB, there is between them in length no conſiderable difference. So that the refracted ray FI concurs with the axis in the point, which is diſtant from the curve ſurface about the quantity of the diameter of the lens.

If the ray of light falls out of air on the convex ſurface of the lens parallel with its axis, as well entering as going out, it undergoes a refraction: For, as in entring, it is refracted on the convex ſurface, it comes under an oblique angle on the plain ſurface. And therefore alſo in the going out of the plain ſurface into the air it is refracted, §. 164. And conſequently the diſtance at which it unites with the axis is ſomewhat leſs than the diameter of the lens. According to baron *Wolfius* in his *Elementa Catoptricæ*, §. 173. *ſeq.* the difference, by which the diſtance of union is leſs than the diameter, amounts to $\frac{2}{3}$ of the thickneſs of the lens. But if this laſt, in regard to the ſphere, from which the lens is taken, is inconſiderable; the diſtance of union is to be conſidered as equal to the diameter of the lens. Yet more rays run to the axis of the lens, when the light falls out of air on the convex ſurface, than when it firſt comes on the plain ſurface.

§. 177. The rays of the ſun collected in the point F, which are incident parallel with the axis ACB, §. 144. have a burning force. And hence the point F, in which the rays of the ſun refracted out of the lens unite with the axis, is called the *burning-point*, and the lens a *burning-glaſs*.

§. 178. If the lens HEK is convex on both ſides, the diſtance of the focus F is nearly equal to the radius, fig. 4. Plate IV. The demonſtration baron *Wolfius* gives in his *German Elem. Diopt.* §. 23. As the burning-glaſſes, convex on both ſides, collect the rays into a narrower ſpace, than thoſe that are convex on one ſide only; ſo alſo their focus has greater force than that of the others. Among burning-glaſſes thoſe of *Tſchirnhauſen* claim the preference, and are deſcribed in the *Acta Eruditor.* for the year 1697. p. 414. *ſeqq.*

§. 179. If a ray PE, fig. 3. Plate IV. is incident on a glaſs ſphere parallel with its axis ACB under 30 degrees; it will be united with the axis behind the ſphere in F at the diſtance of a fourth of its diameter. The demonſtration you find in baron *Wolfius's German Elem. Dioptr.* §. 18.

§. 180. If the rays falling on a lens run diverging with the axis, their focus is farther diſtant from the lens than the focus, which the rays falling parallel with the axis form. This baron *Wolfius* demonſtrates in his *Elementa Dioptricæ*, §. 223.

§. 181. The parallel rays, which go out of a tranſparent medium through a plain ſurface into another, remain parallel alſo in that other, tho' both mediums differ in denſity, fig. 3. Plate III. For, if the rays AC and LC fall perpendicular on the refracting ſurface RCCM, they paſs thro' unrefracted, §. 164. and muſt therefore remain parallel. But if the rays DC and HC fall obliquely on the refracting ſurface, but mutually parallel, the angles of incidence DCC and HCM are mutually equal. For, as the refracting ſurface is to be conſidered as a line, by which the parallel lines DC and HC are interſected; the external angle HCM is equal to the internal DCC. So that alſo the angles of inclination ACD and LCH are mutually equal. For, ACD with DCC makes a right angle; and LCH with HCM in like manner a right angle, which is equal to the other. And ſubtracting equals from equals the remainder is equal. Now the ſines of the angles of inclination have always one and the ſame ratio to the ſines of the refracted angles, §. 166, and 168. And therefore alſo the refracted angles FCG and pCq are mutually equal. But FCG with FCR forms a right angle; as alſo pCq with pCC. And if thus from theſe right angles, which are mutually equal, you deduct the equal angles FCG and *p*C*q*; there remain the equal angles FCR and *p*CC. If two lines CF and C*p* are ſo interſected by a third, that the external angle is equal to the internal; the interſected lines CF and C*p*, as refracted rays, are mutually parallel.

§. 182. If therefore the rays of the ſun fall on a glaſs, plain on both ſides, either under a right or an oblique angle; they will thereby be brought neither to a narrower, nor a wider ſpace. And thus with a glaſs, plain on both ſides, there is no burning.

§. 183. If a ray of light is incident parallel with the axis on a glaſs, concave either on one ſide or on both; the rays will be refracted from the axis, and after refraction ever continue receding farther from it, the farther they proceed. If the glaſs is plain on one ſide, and on the other concave, fig. 5. Plate IV. the ray OH goes unrefracted to the limit H. But here in the exit it is refracted from the perpendicular CH, §. 164. and thus in its progreſs ever removes farther from the axis ACB. If the glaſs is on both ſides concave, fig. 6. Plate IV. the parallel incident ray LN recedes from the axis AIKB as well in the ingreſs as egreſs. For in the ingreſs it is refracted towards the perpendicular, drawn from I through the point of ingreſs, §. 164. Now as this perpendicular recedes from the axis, ſo muſt alſo the refracted ray. In the exit at O the ray is refracted from the perpendicular KP, and thus after refraction recedes ſtill farther from the axis, than after the firſt refraction.

CHAP. IV.

Of the Inflection of the Rays of LIGHT.

§. 184. IF through an aperture you let a number of parallel rays DC and EO, fig. 4. Plate III. fall into a darkened room, and paſs along the edge C of a body ACB; their direction will be ſo changed, as to incline towards the ſide AC, and take the way C*d* and O*e*. The ray DC, paſſing neareſt along the edge C, inclines ſtrongeſt towards the ſide AC; on the contrary, the more diſtant EO, weaker. This change of the direction of a ray of light, raking along the ſurface of a body, is called the *inflection*. The jeſuit *Grimaldi*, who firſt obſerved it, calls it the *Diffraction*. *Newton* has more circumſtantially enquired into it, and deſcribed the diſcoveries he made, book III. of his *Opticks*. If in a darkened room you let a ray of the ſun paſs along between the edges of two knives, which ſtand as cloſe together as poſſible; it ſo divides itſelf at the edges of the knives, that the parts of the ray received on a white paper, exhibit with their light the tail of a comet. The manner of trial *Graveſande* very diſtinctly deſcribes in his *Elementa Phyſices*, T. II. c. 5. From this it is clear, that alſo thoſe particles of the ray, which are not in immediate contact with the edges are inflected. If in a darkened room you let a ray of light fall on a thread or wire, which fully receives or intercepts the ray; the thread or wire caſts a ſhadow; which if you intercept with a white paper at a great diſtance from the thread; it is much broader, than cloſe behind the thread. The reaſon of which is, that the rays, which were to proceed ſtraight on along the ſides of the thread, by the inflection interſect mutually behind it. Which in particular appears from the back of the wire, which ſhould be quite dark, being greatly illuminated at the limits, at which the rays ſhould rake along ſtraight forwards.

§. 185. From this it is evident, that the rays of light have a greater tendency towards the denſer bodies, glaſs and water, than towards the far rarer air: And thus we may explain the refraction in glaſs, water and air by attraction, taken in a mathematical ſenſe, §. 58. And thus the ray of light NF, fig. 1. Plate IV. is refracted in the ingreſs into glaſs out of air towards the perpendicular FF; as the attraction of the glaſs plain at F is ſtronger, than the attraction of the air: And the refracted ray FK is refracted in the egreſs from the perpendicular KI; as in like manner the attraction of the nearer glaſs plain is ſtronger than the attraction of the air. The line FK, in which the refracted ray moves, is therefore a diagonal: And the motion therein ariſes from the force of the ray along NL, and from the force of the attraction along FF, §. 13.

CHAP. V.

Of the Phænomena, ariſing by Means of the different RAYS.

§. 186. WE ſee an object along the line, along which the ray of light comes from it to the eye; as for inſtance, along the line IKH, fig. 1. Plate IV. when the ray goes out of K into the eye at I; or along OKQ, when proceeding from K to the eye at O.

§. 187. And hence by means of refracted rays, bodies appear in a different place, from what they really are in. If the ray FK comes to the eye at K, fig. 1. Plate IV. the body N appears in the place M. If the ray KO falls into the eye, the body N appears in the place Q.

§. 188. If the light, which falls from an object on a plain ſurface under an oblique angle, is refracted once only by it; by the refracted ray the object appears more elevated than it really is. Suppoſe AB, fig. 5. Plate III. to repreſent the ſurface of a denſer medium than air. From the point C under the ſurface, ſuppoſe a ray CA to go perpendicularly towards it, and the other CF obliquely. AC paſſes thro' unrefracted:

Whereas CF is refracted at F from the perpendicular towards D, §. 164. If therefore the eye is in D; the point C appears to it in *c*, and conſequently higher. And hence the ſurface on which a die of glaſs ſtands, appears raiſed quite to its middle: And fiſh and other things under water appear to be nearer to us than they really are: And a body lying on the bottom of an empty glaſs, and viſible either not at all, or in part only, ſo you look obliquely over the rim into the glaſs, will become viſible either in whole or in part, on pouring water into the glaſs, and the eye continuing in the ſame poſition. And hence baron *Wolfius* in his *Elementa Dioptricæ*, §. 86, explains the hydromantick machine, by which the image of an immoveable object may be exhibited to, and withdrawn from the eyes at pleaſure, tho' they remain unchanged in poſition. A ſtraight ſtick, put partly oblique into water, appears broken at its ſurface when looked upon; as all the parts of the ſtick under water appear higher than they really are. If you view the ſtick through the ſide of the glaſs, in which it ſtands; it in like manner appears broken at the ſurface of the water; as the parts under the water appear nearer to the ſide of the glaſs than the parts above the water.

Suppoſe the eye to be within the denſer medium at D, fig. 6. Plate III. and the object without it at C. As the ray CF is refracted on the ſurface AB at F towards the perpendicular, §. 164. So the point C appears by the ray DF, which is carried to the eye to be in *c*; and conſequently farther from AB, and thus higher than it really is. And thus objects in the air appear more remote to the fiſh in the water; and to us the ſtars more elevated above the horizon than they actually are, on the light being obliquely incident. How much the refraction of the light raiſes the image of a ſtar in each degree of elevation, reckoned from the horizon, *De la Hire* has ſhewn in his *Tabulæ Aſtronomicæ*, in a table apart, in minutes and ſeconds, and to be found in *Wolfius*'s *Elementa Aſtronomiæ*, Sect. 349. If a ſtar is ſeen at the elevation of 10 degrees you muſt deduct 5′ 41″. But if obſerved at the height of 20 degrees, you are to deduct 2′ 51″ only. If ſtanding at the horizon, by the refraction it appears, 32′ above it.

The denſer the medium, into which a ray of light is incident out of a rarer, the greater the refraction. The *Dutch* in 1596 ſaw in *Nova Zembla* the image of the ſun ſixteen days ſooner than it could be really ſeen at the horizon in a clear ſky, as being ſtill four degrees depreſſed under the horizon. If therefore the denſity of the air encreaſes and decreaſes, the refraction alſo of the light will be now leſs, again greater;

and an object appears through it, now lower again higher. If we view, for inſtance, through a fixt tube a tower at a diſtance, we obſerve from morning to noon always a higher part; and from noon to evening always a lower part.

§. 189. If a ray of light undergoes a double refraction, when going from a point N out of a rarer matter into a denſer, and out of this again to a rarer: The point, by the refracted ray OK, fig. 1. Plate IV. appears to the eye in Q, and thus lower than it really is.

§. 190. The perpendicular CD, fig. 7. Plate III. which may be drawn from a radiant point C on the mirrour AFB, is called the *cathetus of incidence.*

§. 191. Each object, from which rays fall on a plain mirrour, appears behind it in the point, where the reflected ray unites with the cathetus of incidence, ſo you imagine both lines to be produced through the glaſs, fig. 7. Plate III. Now ſuppoſe either the perpendicular reflected ray CD, or the oblique reflected GF, to come from the luminous point C to the eye; in both caſes C appears not only at the ſame diſtance, but alſo in the ſame point behind the mirrour. This experience teaches. Now this conſtant point of diſtance can be no where elſe but in E, where the cathetus of incidence CDE, imagined to be produced through the mirrour, concurs with the reflected ray GFE. For, the angle of incidence y is equal to the angle of reflection x, §. 150. But the angle o is alſo equal to the vertical angle x. And therefore $y = o$. And conſequently FE muſt concur with DE in E, as FC does with DC in C. And for C therefore to appear without the point E; C could not be ſeen in one and the ſame point and diſtance, on viewing one time along the line CD, and another along the line GF.

§. 192. If you therefore ſee an object C, fig. 7. Plate III. in a plain mirrour, it appears ſo diſtant behind the mirrour in E, as itſelf is really diſtant from the mirrour. For, as CDE is the produced cathetus of incidence, at D the angles are right, and conſequently equal. The angle y is equal to the angle o, and the ſide DF a common baſe to both triangles, and therefore CD = DE.

§. 193. Every body is ſeen under a certain angle. For, both the rays AC and AD, fig. 9. Plate. III. falling from both the extremities of the body CD through the middle of the pupil of the eye A, include at A an angle. This angle is called the *angle of viſion*, and is the meaſure of the apparent magnitude of the ſide CD oppoſed to it. The magnitude which anſwers to the ſide, without being viewed under this angle, is called its real magnitude.

§. 194. The greater therefore the angle of viſion, the greater the object appears. Whereas, the ſmaller the angle of viſion, the ſmaller appears the object. As for inſtance, CD is equal to EF. But as EF is farther diſtant from A than CD; ſo EF appears under a leſs angle EAF than CD, which is ſeen under the greater angle CAD. And hence EF appears leſs than CD.

§. 195. In plain mirrours things appear behind them in their true form and magnitude. Both the catheti of incidence, AC and BD, fig. 8. Plate III. drawn from the object AB to the mirrour FE, as being perpendicular lines, retain therefore conſtantly one and the ſame diſtance from each other, produced never ſo far. Now as *a* and *b* appear ſo diſtant behind the glaſs, as A and B are diſtant from it, §. 192. the line *ab* is not only equal to the line AB, but *ab* appears in the eye G under as great an angle, as is that under which AB would appear, ſtood the eye in *g*, and were the mirrour removed.

§. 196. In convex ſpherical mirrours the images are leſs than the objects repreſented. The catheti of incidence, drawn from the radiant points A and B, fig. 10. Plate III. to a convex ſpeculum GH, go through its centre, if produced; and thus ever approach mutually nearer. If from the point A you look into the mirrour in the cathetus AC; A appears as diſtant behind the convex ſpeculum, as it exhibits itſelf to the eye, when viewed in the reflected ray F*d*. Alſo A in both caſes will be ſeen behind the mirrour at one and the ſame place. And this experience teaches of the point B, when viewed by the eye in the cathetus BC and the reflected ray F*e*. And therefore every point of the object appears behind a convex ſpeculum, juſt as behind a plain one at the place, where the cathetus of incidence, and the reflected ray unite, when imagined drawn through the mirrour, §. 191. Now as both the catheti of incidence, drawn from the extremities of the objects A and B, are nearer each other within the convex ſpeculum than without it; ſo the line *ab*, imaged within the mirrour, is leſs than the real line AB. So that the image in the ſpeculum muſt appear under a leſs angle, than the object without it, on viewing image and object at equal diſtances. Convex mirrours therefore exhibit the objects leſs than they really are.

§. 197. If the convex ſpeculum is cylindrical, and ſtands upright; every object appears in it very long, but extremely ſlender. For, lengthwiſe pure ſtraight lines may be drawn on its ſurface. And thus lengthwiſe it exhibits a plain mirrour. Lengthwiſe therefore objects appear in their true magnitude. But as the mirrour breadthwiſe is convex, it exhibits the objects leſs than they are. An image, which has the length of the thing repreſented, but a leſs breadth, neceſſarily ſhews long and ſlender, when compared with the object. If the cylindrical mirrour is held horizontal, the objects appear broad therein, but extremely ſhort. If the convex ſpeculum is conical, and ſtands upright, the objects ſhew long and ſlender therein, and tapering above, and below much broader. For, lengthwiſe a right line may be drawn on it, repreſenting a plain ſpeculum. And thus the object appears in its length; breadthwiſe are circular peripheries, decreaſing always from the baſe to the vertex. So that the image, which already is ſlender at the baſe, muſt ever turn ſlenderer, the nearer it comes to the vertex. If a conical ſpeculum is parallel with the horizontal line, or is inclined towards it; the objects appear broad and very ſhort, and on one ſide leſs than on the other. There are given anamorphoſes or deformed images, which are again rectified in cylindrical and conical mirrours. The cylindrical you ſet on the deformed image; but the conical in ſuch a manner, that the image encompaſſes its rim. In order to view the image in the conical, you hold the eye over its vertex. *Leupold*'s anamorphotick machine, by which deformed images are made, is deſcribed in the *Acta Erudi-*

tor. for the year 1712, p. 367. The ſeveral ways of delineating deformed images, *Schottus* deſcribes in his *Magia Univerſalis*, in the 3d book of the Opticks, intitled *Magia Anamorphotica.*

M. Leutman in 1729, exhibited at *Peterſburg* on a metal plate by means of a polyedron, the image of the emperor *Peter* II. Without the polyedron there appeared to the naked eye in the middle of the plate the two-headed eagle crowned, which held in the one claw the ſceptre, and in the other the monde. In the middle on the lower part of the plate was ſeen a veſſel with ornaments. Out of the veſſel went a bay-tree, whoſe branches ſpread round the eagle. At the branches hung fruit, which formed the proper parts of the image. Round the bay-tree were to be ſeen the arms of *Aſtracan*, *Caſan*, *Siberia*, and other kingdoms ſubject to *Ruſſia*. Under the veſſel ſtood written on a flying or waving label; VIVAT PETRUS II. IMPERATOR. On looking through the polyedron on this plate, there appeared the image of the emperor *Peter* II. on a white plate. From the ſhoulder hung down the ribbon of the order of St. *Andrew*. The head was braided round with bay-berries. To the right ſtood a table, on which the crown and ſceptre lay. The other images, the bay-tree, the veſſel, the arms, and the eagle were not to be ſeen at all. How *M. Leutman* ordered this anamorphotick repreſentation, he himſelf deſcribes in the *Comment. Petropolit.* T. IV. p. 208, *ſeqq.*

§. 198. The ſmaller the image of a thing in a convex mirrour, the bigger is it behind a concave mirrour, when the thing or object lies between its ſurface and focus. Suppoſe the line *ab*, fig. 10. Plate III. which was an image of AB, to be viewed in a concave ſpeculum GH by the eye in the centre C; you ſee *a* and *b* by the rays *ba*C and *fb*C, as along catheti of incidence, reflected from the concave ſurface, and conſequently behind the mirrour. But theſe catheti run on in ſuch a manner, that their intermediate ſpace becomes always larger. And thus the image AB muſt appear far larger behind the glaſs, than the object *ab* ſtanding before it.

§. 199. If a burning body ſtands in the focus of a concave ſpeculum, the rays reflected from its ſurface run on parallel. For, the ray FG, fig. 1. Plate III. going from the focus to the ſurface, falls on the point G, from which the incident ray KG comes to the focus. So that FG muſt be reflected from the point G along the ſame line, in which KG falls diſtant on the ſpeculum, and thus in its reflection run parallel with the axis, and with the ray reflected along it.

§. 200. So that a burning mirrour throws the light of a burning body, ſtanding in its focus, through a great diſtance, and can illuminate a far diſtant object. If theſe reflected rays fall in a certain diſtance on a greater burning mirrour; they are reflected from its ſurface into a point, in which they have a burning force.

§. 201. If an object is farther diſtant from the ſurface of a concave ſpeculum than its centre; an eye, which in like is at a greater diſtance than the centre, ſees the image of the object hovering reverſed between the centre and the ſurface of the ſpeculum. For, the incident ray ED, fig. 11. Plate III. is reflected to F; and drawing from E through the centre C the cathetus EH; in H is the point, in which the point E appears. The incident ray FD is reflected to E; and drawing from F through the centre the cathetus of incidence FG; G is the point, in which the point F appears. And thus GH is the reverſed image of EF, and appears hovering between the ſurface and centre of the ſpeculum in the free air.

§. 202. If the rays of light, falling from an object through a tranſparent medium, are ſo refracted through it, that the angle, which they form in the eye, is greater than the angle, under which the unrefracted rays unite in the eye; the object appears bigger through the refracting matter or medium, than without it, ſo the object in both caſes has the ſame diſtance from the eye, §. 194.

Now this may happen, fall the rays of light either through a plain or a convex ſurface. By the plain ſurface the image of the object is enlarged, when the eye is in a rarer matter than the object to be viewed. Suppoſe as well the object AB, fig. 12. Plate III. as alſo the eye at G to be in free air. So that the object AB will appear under the angle AGB, where the rays AG and BG fall into the eye. But if the object AB lies in water, or in other fluid, tranſparent or denſer media than the air, in which the eye is; the object appears under the greater angle AGC. For the oblique ray BE is refracted in the exit at E from the perpendicular EF, §. 164. And therefore the eye ſees the extremity B along the line GEC, §. 186. and conſequently the object under the angle AGC.

And ſo the ſun has an elliptical form, when juſt going under the horizon. The horizontal refractions, which are the greateſt of all, then raiſe his under limb much higher than the upper, and make the perpendicular diameter, compared with the horizontal, which is not thus affected, the ſmaller. And hence ariſes the elliptical figure. But it is ſomewhat exceeding rare, thus to ſee the ſun's diſk a few degrees above the horizon. Which ariſes hence, that the refractions a little above the horizon decreaſe very quick up to the zenith. Yet *M. Mairan* on *June* 28, 1733, obſerved the ſun at the height of about 10 degrees very diſtinctly of an elliptick form, as he relates this obſervation in the memoires for the year 1733. And thus there was then in the atmoſphere, at an elevation of 10 degrees, a refracting matter of an intenſeneſs and quantity unuſual, near the horizon.

The tranſparent matters, with convex ſurfaces, are in regard to their ſpecies, either fluid as water; or ſolid, as glaſs: And in regard to their figure, either ſpherical or lenticular. How and wherefore objects appear bigger through theſe matters, than when ſeen without them at an equal diſtance, we may explain as follows. If the eye in F, fig. 13. Plate III. ſees the object MB without an interpoſing glaſs; MB appears under the angle MFB. But if a convex glaſs interpoſes between the object MB and the eye in ſuch a manner, as that its focus is in F, and conſequently falls into the eye; MB appears under the angle MFC, and therefore bigger. At the ſame time it appears, that the object MB through the convex glaſs exhibits itſelf in the ſame poſition, in which it is ſeen without it. As the angle MFB is equal to the angle LFE, and the angle MFC to the angle LFN, ſo the apparent amplification of the object is always the ſame, be the object MB much or little diſtant from the glaſs, ſo only the diſtance itſelf is no hindrance to the viſibility. But MB, as the diameter of the real magnitude is to MC, the diameter of the apparent, or the magnitude appearing through the glaſs, as LF the diſtance of the eye, or focus from the glaſs, to FM the diſtance of the eye, or focus from the object. For as the curvity LN differs inconſiderably from a right line, ſo LN is parallel to MB. But both theſe lines are alſo mutually equal. By the doctrine of triangles, in which a line is drawn parallel to the baſe, LN, and conſequently MB, is to MC, as FL to FM.

If you uſe glaſs lenſes, or glaſs ſpherules for viewing a ſmall and near object; ſuch lenſes and ſpherules are called *magnifying glaſſes.* If a magnifying glaſs conſiſts of a ſingle lens, or a ſingle ſpherule; it is called *ſingle.* The objects to be viewed are put either in the focus, when the viewing eye is ſound, and conſequently capable of ſeeing diſtinctly as well far off as near at hand; or between the focus and the lens, if the eye diſtinguiſhes near objects diſtinctly. The eye at G, fig. 14. Plate III. is by far nearer the lens, than the object AB. If the object lies in the focus; a ſound eye ſees it not only under a greater image, but alſo in full diſtinctneſs. But if you remove the lens, the object appears undiſtinct to the eye, ſo eye and object continue fixed in the former poſition. But if you remove the object eight inches diſtant from the eye, it again appears thereto as diſtinctly, as when laid in the focus, and the lens were between it and the eye. The diameter of the object lying in the focus you may call AB, and the diameter of the magnified image IK, the diſtance of the focus FC, and that of the image FH. As the diameter AB is parallel to the diameter IK; ſo by the doctrine of triangles, in which a line is drawn parallel to the baſe, AB is to IK, as FC to FH. As the diameter IK of the image appears as diſtinct, as the object, when viewed by the eye without the lens at a diſtance of eight inches; ſo the diſtance FH, at which the object is ſeen, is to be deemed equal to eight inches. As many times therefore as the diſtance FC of the focus is contained in FH the diſtance of eight inches, ſo many times is the diameter AB of the object contained in the diameter IK of the image. And thus if the focus falls an inch diſtant from the lens, the diameter of the object appears through the lens eight times bigger than without the lens. If therefore the diſtance of the focus were $\frac{1}{10}$ inch, the diameter of the object would appear 80 times greater.

If the rays KF and NF, fig. 13. Plate III. which are concentred from the object OC by the lens KLN into the focus F, proceed farther from it, and fall on a white wall in a darkened room; they exhibit the object inverted thereon. If the object, ſtanding or lying in the focus, is by means of a convex glaſs enlightened by the rays of the ſun; its image may be viewed diſtinct and magnified on the wall. Its diameter to that of the object in the focus, is as the diſtance of the wall from the magnifying lens to the diſtance of its focus. Theſe ſorts of magnifying-glaſſes are called *ſolar microſcopes.*

If the image CO, fig. 13. Plate III. comes into the focus of another lens; it appears in the eye inverted behind it, and bigger than the image, formed in the eye, on viewing the object by a ſingle lens. The lens, which immediately receives the rays from the object, is called the *object-glaſs*; and the lens, through which the eye ſees, the *eye-glaſs*, or eye-lens. From a combination of lenſes, in which the image behind the focus of the one comes into the focus of the other, ariſe compound magnifying-glaſſes, in as far as near objects may be viewed thereby. How ſuch magnifying glaſſes are to be executed and uſed, baron *Wolfius* gives particular directions in his *Element. Dioptr.* §. 439. *ſeqq.* and Mr. *Hertel* in his *Inſtructions for grinding glaſſes,*

p. 136. *ſeqq.* Then p. 150. *ſeqq.* Mr. *Hertel* ſhews, by means of a micrometer how to meaſure the diameter, magnified by the microſcope; or to diſcover, how much the diameter is amplified by the magnifying-glaſs.

In like manner, from the combination of object and eye-lenſes, teleſcopes ariſe, whereby objects, undiſtinguiſhable on account of their diſtance, become diſtinguiſhable to the eye, and appear to be brought nigh; ſuch a teleſcope is called *aſtronomical*, when put together of one convex object glaſs, and one convex eye-glaſs only. It exhibits the object inverted. For, the object-glaſs CB, fig. 7. Plate IV. is ſo covered, that the perpendicular incident ray *b*AB goes through its middle; whereas the ray *c*A, which comes from the one extremity of the object, interſects the ray *b*A at A in the focus, and falls on the lens CB at C under an oblique angle. By the refraction, therefore, it is behind the glaſs parallel with BKFI, and in the eye-glaſs at E ſo refracted, as at G to come into its focus. And thus the eye in G ſees the extremity *c*, which without glaſſes appears to it to the right, along the line GE, §. 186. and conſequently to the left, and therefore the object inverted. Hereby the image of the diſtant object is ſo magnified, that the ſemidiameter of the object, ſeen with the naked eye, is to the ſemidiameter ſeen through the teleſcope, as the focal diſtance IF of the eye-glaſs, to the focal diſtance AB of the object-glaſs. The demonſtration of this baron *Wolfius* gives in his *Elementa. Dioptr.* §. 358.

Inſtead of object-glaſſes Dr. *James Gregory*, and Sir *Iſ. Newton*, have taught to uſe metalline concave ſpecula. Such teleſcopes are far ſhorter than the others, and magnify quite as well. In the *Gregorian* teleſcope the eye-glaſs is inſerted lengthwiſe at one end of the tube, but in the *Newtonian* at the ſide thereof.

In order to have the object, to be viewed by a teleſcope, which is put together of convex lenſes only, to appear in that ſituation, in which it would appear to the naked eye; four convex lenſes are ſo combined together, that the ray *a*QA, fig. 8. Plate IV. incident from the one end of the object and croſſing the axis *b*I in the focus Q, falls on the lens AB under an oblique angle; and after refraction runs parallel with the axis IL behind the lens AB on the other CL; by the refraction it is brought on the third EF at F under an oblique angle; from which in a parallel direction with the axis NO, it comes on the fourth GH; and from this at length it is refracted into the focus P. For thus, the extremity *a* is ſeen to the right along

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the line PH, and conſequently alſo ſeen through the teleſcope to the right. Such teleſcopes are called *terreſtrial*, as being fitter to view diſtant objects on the earth with, than the aſtronomical.

§. 203. If an object appears by refracted rays under a leſs angle, than without, it appears ſmaller through the refracting matter or medium, than if viewed at a like diſtance with the naked eye, §. 194.

The ſurfaces, through which objects appear ſmaller to the eye, are only of two ſorts, plain and concave. The plain diminiſh the image, if the rays from the object are refracted out of a rarer into a denſer medium, and therein come into the eye. Suppoſe the object AB, fig. 9. Plate IV. to be in air, and the eye at F in water. Were the eye in like manner in air, it would ſee AB under the angle AFB. But being in water, the ray BG at the ingreſs into the denſer medium is refracted towards the perpendicular, §. 164. and therefore paſſes by the eye. But if the ray BD is in like manner refracted at D towards the perpendicular, it comes into the eye at F. So that it ſees the extremity B along the ray FDC, and conſequently the object under the ſmaller angle AFC.

How an object appears ſmaller through a concave glaſs, may be underſtood by fig. 5.

Plate IV. Suppoſe the eye to be in *n*. If it views the object AF without an interpoſing concave glaſs, the diameter appears under the angle A*n*F. But if the concave glaſs be conveyed between the eye and object; the ray F*n* is refracted from the eye, §. 164. Whereas the ray FH by the refraction comes into the eye at *n*. Now the diameter of the object is ſeen along the axis and the line *n*GO, and conſequently under the ſmaller angle A*n*O.

A teleſcope, which is put together of a convex object lens, and a concave eye-lens, is called a *Dutch* or *Galilean* tube. The reaſon of the firſt appellation is, that it was firſt known and conſtructed in *Holland*: But of the ſecond, that *Galileo* was the firſt who deſcribed the obſervations he made therewith. Objects appear through it in the very ſame poſition, in which they appear to the naked eye. For, though the ray, proceeding from the extremity of the object to the right, falls on the convex lens to the left, and after refraction runs parallel with the axis; yet in the concave lens it is ſo refracted from the axis, that the image of the extremity to the right is ſeen along a line, which runs to the right. And though the concave lens diminiſhes the image of the object; yet on account of the combination with the convex object-lens it is magnified. But the diameter, which appears in the eye without ſuch a teleſcope, is to the diameter, which is imaged in the eye with it, as the diſtance of the imaginary or virtual focus of the concave lens, to the diſtance of the real focus of the convex lens. A diſtinct demonſtration of this you find in baron *Wolfius*'s *Elementa Dioptr.* §. 340.

§. 204. If a ground glaſs conſiſts of ſeveral plain ſurfaces, which are ſo united, that the glaſs has ſeveral angles, it is called a *polyedron*, or *multiplying glaſs*. So many angles as it has, ſo often an object, viewed therein, appears. Suppoſe there are three ſides, GA, AB, BF, fig. 10. Plate IV. and in C a ſtar. From the ſtar rays fall on each ſide, which are refracted by each ſide towards the eye O. So that it ſees the ſtar along the lines OHC, OKC and OIC, §. 186. and conſequently three times. As the ſides or ſurfaces are plain, and the rays fall out of air into glaſs, and again out of glaſs into air; ſo the object appears neither bigger nor ſmaller than it is ſeen with the naked eye at a like diſtance. But if a glaſs, plain on both ſides, has ſmall grooves or pits on one ſurface; it is called a *polyoptron*, and repreſents, indeed, an object in like manner multiplied, but on account of the concave lenſes, ſmaller than it appears to the naked eye.

§.

§. 205. The combinations made of mirrours and lenſes are called *catadioptrick* machines. To which claſs belong the *Gregorian* and *Newtonian* teleſcopes, the *Newtonian* reflecting magnifying glaſs, the polemoſcopium, the hydromantick veſſel, the magick lantern, and the helioſcopium. The preparation of theſe inſtruments baron *Wolfius* directs in his *Elementa Dioptricæ*, c. 8.

CHAP. VI.

Of the Nature of LIGHT.

§. 206. IN ſo far as light is conſidered as a ſpecies of matter, §. 144. it muſt either flow from the ſun and other luminous bodies; or conſtantly exiſt in the ſpace between the ſun and the ſtars.

§. 207. *Newton* holds it for an efflux of a matter from the ſun and other luminous bodies. But this opinion, for the following reaſons, is unmaintainable. The action of light from the ſun to the earth is compleated in a ſpace of ſeven or eight minutes. For, the ſun S, fig. 1. Plate V. being between the earth T and *Jupiter* I; the light comes from the firſt ſatellite of *Ju-*

piter after its emerſion out of his ſhadow, almoſt 15 minutes later to the earth, than when the earth T is between the ſun S and jupiter I. In the firſt caſe, the earth is by the whole diameter of its orbit more diſtant from jupiter; and in the ſecond, by that whole diameter nearer thereto. And thus if light finiſhes its action in 15 minutes through a way, which is equal to the entire diameter of the earth's orbit; we muſt allow for the time of this action, through the ſpace from the ſun to the earth, the ſemidiameter of the earth's orbit, between ſeven or eight minutes. But the diſtance of the earth from the ſun amounts to 22000 ſemidiameters of the earth. As difficult as it is to conceive that a real matter ſhould ſtream through ſo diſtant a ſpace in ſo ſhort a time; juſt ſo difficult is it to comprehend, how the rays of light, which are deemed to be actual matter in motion, ſhould not obſtruct, reſtrain and intangle each other in their motion; when in ſo great a degree of velocity they either run againſt, or croſs each other in a narrow aperture, §. 147. Did the rays of light, as an actual matter, move ſo quick; tranſparent bodies could have no coheſion in their parts, and conſequently not conſiſt. For inſtance, a glaſs is tranſparent in all its ſides, parts and points. If therefore, the tranſparency of bodies aroſe hence; *viz.* that the matter of light flowed in right lines through every point; there could not be the ſmalleſt particle in the whole glaſs, through which there would not be a rectilinear way open to the others. And then how ſhould theſe parts in any manner touch each other, or hang together?

§. 208. With theſe reflections profeſſor *Euler* in his *Nova Theoria lucis & colorum*, combats *Newton*'s notion; and on the contrary, explains the nature of light by a motion, propagated through a ſubtle matter, which fills up the mundane ſpace between the ſtars, and is otherwiſe called *æther*. When in the definition, §. 144. I called light a matter, I at the ſame time hinted, that ſometimes motion was thereby underſtood: And hence it is evident, that in the main I depart not from profeſſor *Euler*. And if thus I now ſpeak of the nature of light, the enquiry regards the ſubtle matter, which profeſſor *Euler* ſays, light is propagated by. *Newton* wanted to exclude all matter, how ſubtle ſoever, from the mundane ſpace. The reaſon was, his apprehending, the planets and comets might be retarded in their motion by ſuch a matter. But what *Newton* apprehended from the mundane ſpace being full, or a plenum, he could not avoid by his own opinion about light. For, if light be a matter flowing from the ſun and fixed ſtars; the mundane ſpace muſt needs be filled therewith, and conſequently the motion of the planets gradually weakened. The *Newtonians*, indeed, give out the reſiſtance, which the planets meet with in the ſtreaming rays of light, for ſo inconſiderable, that the effect thereof would become obſervable only in a long tract of time. But by this very limitation they give to underſtand, they no longer combat the oppoſite opinion: For, ſo fine or ſubtle ſoever their ſtreaming rays are, ſo ſubtle alſo is the æther, or the pure celeſtial air.

§. 209. *Deſcartes* in his *Principia Philoſophiæ*, P. III. §. 55. 63, 64. filled the mundane ſpace with the perfectly hard globules of his ſecond element, in which one globule is ever in the cloſeſt contact with another; and he aſcribes to them the force and action of light thus, that thoſe, lying at the ſun and fixed ſtars, are propelled from theſe laſt; and that the motions impreſſed on the firſt globules are propagated by the others in right lines to the greateſt diſtances. Had *Deſcartes* known, that it takes ſeven or eight minutes, ere the pulſe or puſh of the ſun on the globules, contiguous thereto, could be carried through a whole row quite to the earth, he would have deviſed certain void interſtices between his globules. For in this manner, a globule would have always required a ſpace of time, in order to come through ſuch an interſtice to the other. But notwithſtanding this, we could not explain from deviſing theſe globules, how it were poſſible, for the motion of light to diffuſe itſelf equally ſtrong every way in right lines. For, the globules muſt have had a poſition, that the right lines, in which the motion was to be propagated, ſhould paſs thro' the centres of the globules. But this is not poſſible.

§. 210. We ſee ourſelves therefore neceſſitated with profeſſor *Euler* to hold light, or the matter of light, when taken for a ſpecies of motion, for a fluid and elaſtick matter, diffuſed through the whole mundane ſpace. In *Newton*'s *Principia*, l. 2. propoſ. 42. we have an objection, which deſerves to be examined. If a ſound, ſays he, forces through a window into a room, it may be heard in every corner thereof. It ſhould thus appear, it was propagated every way from the place of the window, where it comes in at, by the air, as an elaſtick matter. On the contrary, a ray of light, admitted through a narrow hole into a dark room, takes one ſingle way only, producing light in one ſingle right line. But it is a miſtake, that ſound diffuſes itſelf every way, after having forced through a ſingle opening into the room. So ſoon as it is excited before the window, it forces not only through the opening made, but alſo through every other part of the wall, which admits it through juſt as well, as the parts of a glaſs, through which light acts.

§. 211. How light, or æther, is put into motion, may be explained as follows according to *Euler*: Take a body EAF, fig. 2. Plate V. which vibrates in the manner of a ſtring, and faſtened at E and F, ſtretch it to A. From A to O ſuppoſe an elaſtick matter to lie in a right line, in which all the parts are in equilibrio, none being either denſer or rarer than the other. If the ſtretched body be left to its own force, it ſwings out to E*a*F, and drives the matter from A to *a*. But hereby the parts, that lie out above *a*, are brought cloſer together, or made denſer. The particle *a* is denſeſt of all. From *a* forwards the denſity continues ever decreaſing. Suppoſe the vibration to extend its effect to B only. And thus from B to O all the parts remain in their natural denſity and elaſticity. As the particle *a*, on account of its greater denſity, is more elaſtick than the reſt; ſo it muſt expand itſelf towards O, and hereby bring the following cloſer together, continue the ſtring in its poſition E*a*F; or turn it back towards A. If *a* expands itſelf towards O, its denſity continues gradually decreaſing, till it again acquires its former natural denſity. But as *a* begins to expand, ſo B, which before was in its ſtate of natural denſity, is as well compreſſed;

preſſed, as alſo expelled its place. Suppoſe it carried to *b*; and thus in *b* is the greateſt compreſſion. But at the ſame time alſo the particles lying out above *b*, are put out of their ſtate of natural denſity. Suppoſe this change to ceaſe in C, and the denſity there to be in its natural ſtate. But if the particle *b*, on account of its encreaſed elaſticity, expands itſelf, the particle C will be expelled its place; which ſuppoſe come to *c*. And in this manner the particles from *c* to D will be made denſer. The particle *c* in like manner expands itſelf by means of its greater elaſticity. And hereby D is expelled its place. In this manner the expanſion ever proceeds farther on, and comes at length to the limits O. And thus it is hence clear, that the ſtrongeſt compreſſion, made by the vibration of the ſtring in the particle *a*, is ever gradually propagated farther along the line AO. So long as this propagation continues, one part is ever more compreſſed and elaſtick than another. But as the parts of the line forwards from *b* to C are put out of their natural denſity; ſo the very ſame thing happens to the parts backwards from *b* to B, ſo they are not compreſſed by a new vibration of the ſtring. Such a change, in which a part of an elaſtick matter is moved out of its place, and at the ſame time made denſer, is called by *Euler* a *pulſe* or *ſtroke*.

§.

§. 212. The denſity of light or æther, is ſo inconſiderable, that the reſiſtence, which the planets undergo thereby in their courſe, remains unobſervable for years together. How little the motion of the planets is thereby retarded, profeſſor *Euler* in his diſſertation *de relaxatione motus planetarum*, has examined and calculated. At the ſame time he there ſhews, how æther is to be deemed rarer than air 400,000,000 times.

§. 213. The fineneſs or ſubtlety of the particles of light gives us to underſtand, that the parts of the ſun's ſurface muſt be highly ſubtle. Otherwiſe they would be incapable to puſh the inconceivably ſmall parts of light.

§. 214. As the action of the ſun on light is inceſſantly laſting, the parts of its ſurface muſt be in a continual motion: So that they conſtantly produce one ſtroke after another in ſucceſſion, and thus move to and fro. This happens with ſo great a degree of velocity, that the effect thereof extends in eight minutes over a ſpace of 22000 ſemidiameters of the earth. The parts therefore of the ſun's ſurface muſt be in a violent vibrating motion. For a vibratory tremor is aſcribed to a body, when moving to and fro ſo quick, that both motions are ſcarce diſtinguiſhable by the eye.

§. 215. A body, whoſe parts put light into motion, is called *luminous*. Now as the ſun would not be luminous, were not the parts of its ſurface highly ſubtle, and endued with a violent tremulous motion; ſo all luminous bodies muſt conſiſt either all over of ſuch parts; or at leaſt have ſurfaces, whoſe parts are of this diſpoſition. Of the firſt ſpecies is flame; of the ſecond, glowing bodies, and other luminous matters, as rotten wood, glow-worms, certain millepedes, the dactyli.

§. 216. As light becomes active by the pulſe or ſtroke, which the violently tremulous parts of a luminous body excite therein, §. 211, 214. So rays of light ariſe, §. 144. when ſuch pulſes are propagated in right lines by the light or æther. And thus the denſity of the rays conſiſts, in that in a determinate ſpace a greater number of lines with ſuch pulſes concurs than in another of a like magnitude. The power or intenſeneſs of light, §. 146. in the focus of a concave ſpeculum, or burning-glaſs, §. 156, 177. ariſes therefore hence, that in the ſmall ſpace, which the focus takes up, juſt as many pulſes concur, as are in the large ſpace at the ſurface of the concave ſpeculum, or burning glaſs.

§. 217. If any one ſhall hold the rays of light for matters, that flow from the luminous body; this objection lies againſt him, that theſe matters muſt hinder each other in their motion, either when they run againſt, or croſs each other, §. 207. The explication now given, ſeems ſubject to a like difficulty. Might not what are called pulſes or ſtrokes, §. 211. in like manner hinder each other, when either running againſt each other, or propagated in lines, that croſs or interſect? But the experiments, which are made with elaſtick bodies, ſhew very diſtinctly, that in ſuch pulſes or ſtrokes we have no ſuch impediment to apprehend, §. 86. 88. 90.

§. 218. As light is a fluid and inviſible matter, §. 144. and in the focus of a concave ſpeculum and burning glaſs ſets combuſtible matters on fire, and melts other fixed bodies; ſo it ſhould appear to be a fire, §. 121. This however admits not of a full degree of certainty. For, tho' bodies lying in the focus are expanded, when the power of light acts upon them there; yet it ſtill remains unknown, whether this expanſion ariſes from the ſpace, which a body melted in the focus occupies, having by the light acquired a greater maſs? A body may be expanded by its own proper fire, which is united with all its parts, when it is put in motion. And this may happen by rubbing only, without a fire from without, needing to force into the body, §. 128. Perhaps, the light in the focus does nothing more on fixed and fluid matters, than by the number and intenſeneſs of its ſtrokes, §. 211. to rouſe the fire impriſoned in theſe matters. *Du Cloſs* put a pound of regulus of antimony, ſtamped to a powder, into an earthen veſſel in the focus of a concave ſpeculum. This powder gave forth a whitiſh and thick fume, and in an hour's time was turned as it were to an aſh, and encreaſed about a tenth of its former weight. From this 'tis concluded, that the rays of the ſun, like the fire lying concealed in bodies, whereby in like manner their weight is encreaſed, have a certain degree of gravity with them. Were this the caſe, we ſhould have ſufficient reaſon to deem light a fire. But it is not yet put out of all diſpute, that fire, by its maſs and matter gives any additional weight to bodies. Perhaps, by its violent motion it only opens ways into minerals, by which a certain heavy matter forces into the ſmelted bodies, and blends itſelf with them. M. *Gmelin* has made an enquiry into this matter, which he has publiſhed in the *Commentarii Petropolitani*, T. V. p. 263. *ſeqq.*

CHAP. VII.

Of the Colours of LIGHT.

§. 219. IF a ray of light is admitted through a round narrow opening into a darkened room, it forms on the wall a white circle. But if on its way in the dark room, before it reaches the wall, it is intercepted by a triangular glaſs priſm; in paſſing through this laſt it is parted into a number of rays, which differ from each other as well in the manner of their refraction, as alſo in colour. The experiments, by which *Newton* attained to this diſcovery, he deſcribes in his opticks. The principal rays, which are moſt diſtinguiſhable from each other, are in number ſeven. The ſpace PT, fig. 3. Plate V. which the rays ſeparated by the priſm, illuminate on the wall with their colours, is oblong, and at both extremities of its length round. The colours appear in circles, which all together have equal diameters, but loſe themſelves in, or run into each other. The ray P has the greateſt refraction, and exhibits a violet-coloured circle A. The ray T undergoes the leaſt refraction, and forms a red circle G. Above the red circle

G ſtands a gold, or orange yellow F; above F, a ſulphur or citron yellow E; above E, a green D; above D, a bright or ſky colour C; above C, a dark blue, or purple colour B.

§. 220. The reaſon of the difference of the colours and refractions is by no means in the priſm itſelf. For, none of the ſeven rays admit any change, by a new refraction, either in colour or in the manner of refraction. So diſpoſe a ſtand, that a white paper faſtened thereon, may be raiſed and lowered; with an inciſion behind it in the ſtand, in which a ſhutter may move up and down. If you let one of the ſeven colours, diſtinguiſhable on the white paper, fall through the inciſion on a priſm placed behind; it will, indeed, in its ingreſs and egreſs be refracted, but enlighten the white wall ſtanding behind it with the very ſame colour, with which before the ſecond refraction, it was diſtinguiſhable to the eye. If all the ſeven rays, one after another, be ſuffered to paſs through the ſmall opening in the ſtand, and the ſecond priſm, and you give heed to the quantity of their refraction among themſelves; you find, that the violet ray, juſt as behind the firſt priſm, is moſt refracted; and the red, leaſt. If all the rays, which in going out of the priſm part aſunder, are collected by a burning glaſs; they form in the focus on a white paper a bright point or ſpot. But if you move the paper farther from the focus, that the rays, collected therein, may again part aſunder; the ſeven colours come again to view on the white paper. They ſtand, indeed, in inverted order; as having been ſo refracted by the burning-glaſs, that the uppermoſt ray appears undermoſt; and the undermoſt, uppermoſt. But yet they follow each other in the very ſame order they obſerve among themſelves, when collected by no glaſs behind the priſm. If we view the rays, collected in the focus through another priſm, we diſtinguiſh by its refraction in like manner all the ſeven colours. They may even be diſtinguiſhed through a priſm, when collected in the focus of a concave ſpeculum.

§. 221. And therefore one ſort of rays muſt ever have more or leſs force than another. The greateſt is in the red, as it admits the leaſt degree of refraction. And then the query is, whence the degree of force or intenſeneſs might ariſe? Either the parts of light muſt differ in denſity from each other; or the number of the ſtrokes following upon each other, §. 211. be greater in one ray of light in an equal time than in another. The firſt ſeems repugnant to the nature of an elaſtick fluid matter. For, ſuppoſing one part denſer than another, it would by its intenſer degree of elaſticity ſo expand itſelf againſt the rarer, as ſoon to become of equal denſity. And thus it is more probable, that one ray of light has a greater degree of intenſeneſs than the other; if in the time, that the pulſes are propagated in both, in the one more follow upon each other than in the other. Take, for inſtance, two lines ABC and DEFG, fig. 4. Plate V. each of which is two inches long. Suppoſe from A to B one inch, and in like manner from D to F one inch. In both ſuppoſe a ſtroke to ariſe at the ſame time. The ſtroke at A in a ſecond to reach to B; and the ſtroke at D, in a ſecond to F. And thus in equal times both may perform an equal way. In the firſt line reach the ſtroke in a ſecond to B; a new one may take riſe at A. On the contrary in the ſecond line a new ſtroke at D may ariſe, when the firſt ſtroke of this line is in half a ſecond in E. From D to E may be half an inch. So that the intervals between two ſtrokes in the firſt line are greater; and in the ſecond leſs. But the following ſtroke may be ſo quick, as the preceeding. At the end of the ſecond line at G the ſtrokes come thus quicker on each other, than at the end of the firſt line at C. Now if the ſaid intervals be ſo ſmall, that the following ſtroke acts on its next preceeding; the preceeding will neceſſarily be heightened. And though thus the firſt ſtroke ariſen at A comes in the very ſame time to the point C, in which the firſt ſtroke excited at C reaches the point G; yet the power of the ſtroke in G is greater than the power or intenſity of the ſtroke in C.

§. 222. The red ray therefore is the leaſt; and the violet, the moſt refracted: As in *that* the ſtrokes follow on each other the quickeſt; and in *this* the ſloweſt.

§. 223. If therefore the light, or æther is every where of equal denſity in its parts, the difference of colour in the refracted rays may thence be accounted for; *viz.* that one ray of light conſiſts of a greater number of ſtrokes than another: And thus, for inſtance, the rays called red, oftner touch and ſtrike the eye, then in an equal time it is touched by thoſe called violet rays. And thus colours are properly nothing elſe but motions, excited in the eye by the ſtriking light.

§. 224. The tremulous motions of the moveable parts of a luminous body, from which the ſtrokes in the light have their riſe, muſt therefore be ununiform or variable: Whether it be, that each part vibrates now quicker, again ſlower: Or, that in each point are ſeven parts, one of which has ever a different degree of velocity from the other, but yet conſtantly retaining the velocity peculiar to it. The laſt appears to profeſſor *Euler* to be repugnant to the nature of a burning body, where the violent motion of the fire allows of no ſuch uniform connection of the parts.

§. 225. If we allow the length of the image, which conſiſts of the ſeven colours, §. 219. 360 equal parts; the red colour extends to 45; the gold-yellow to 27; the ſulphur-yellow to 48; the green to 60; the ſky-colour to 60; the purple-colour to 40; and the violet-colour to 80 ſuch parts.

§. 226. The ſeven ſpecies of rays may be blended together in a twofold manner. You may produce colours, that as well reſemble ſome of the primitive colours, as that quite differ from them. But none of theſe compound colours, in the manner of the primitive is unchangeable, when either made to fall, or when viewed through a priſm. Thus the mixture of the red and ſulphur-yellow colours gives a gold-yellow, which differs in nothing from the primitive gold-yellow. From the mixture of the ſulphur-yellow, green and ſky-colour, or azure rays ariſes a green colour, which differs ſomewhat from the primitive green.

PART V.

Of QUICKSILVER.

CHAP. I.

Of the Properties of QUICKSILVER.

§. 227. QUICKSILVER, or mercury, is a fluid matter, whoſe ſpecifick gravity is to that of water without air as 14019 to 1000, and conſequently about as 14 to 1. And hence on putting the hydroſtatical fork, fig. 6. Plate XIV. with the one leg AB into a veſſel of quickſilver, and with the other CD into a veſſel of water, and pulling up the piſton E; the water in CD, by the preſſure of the air, will be forced up 14 times as high as the quickſilver in AB. Quickſilver is commonly found in the mines mixed up with ſulphur, or with a loamy and ſtony matter. But at times it is found actually running, and then by way of diſtinction called *virgin mercury*. As it wets not ſeveral things that come in contact with it, it is called by ſome *aqua Sicca*.

§. 228,

§. 228. There has not to this day any degree of cold been known, by which quickſilver has loſt its fluidity. As the *French* academicians who meaſured a degree of the meridian at the polar circle, were in the month of *January* in 1737 at *Tornea*; the cold was ſo intenſe, that the ſpirit of wine in the thermometer was froze; as M. *Maupertuis* relates in his book on the figure of the earth: Whereas, the mercury continued fluid. In *Reaumur*'s mercurial thermometer, in which in the cold winter of 1709, the mercury at *Paris* ſtood 14 degrees under the freezing-point, at *Tornea* it fell quite to 37 degrees. A ſtill ſeverer degree of cold profeſſor *Gmelin* mentions in the firſt part of his travels to *Siberia*. As on *December* 6, 1734, in the town *Jeniſeiſk* he obſerved the depth of the quickſilver in the thermometers, he found it 120 degrees according to *Fahrenheit*'s diviſion, §. 123. n. 1. under the mark O, which in *Deliſle*'s thermometer make 277 degrees, §. 126. And notwithſtanding, it continued fluid.

§. 229. By fire mercury reſolves into a ſubtle fume, which conſiſts of ſmall globules, that are quickſilver ſtill; as experience ſhews, on catching the fume with wet leather. But the degree of heat, whereby quickſilver is volatilized, muſt be greater than that, in which water boils, §. 123.

§. 230. If wrapt up in linen, and held over ſmelting lead, it turns fixed, ſo as to bear rubbing. This change is called its calcination. As from the lead in ſmelting, nothing but fume goes off: Dr. *Neuman* in his *Chymiſtry*, T. I. P. I §. 6. c. 3. §. 10. holds the fume ariſing from the lead for the cauſe of this calcination; as forcing in between the parts of the quickſilver and adhering to them, and thereby ſtrengthening their mutual coheſion. In like manner, §. 11. he ſhews how quickſilver is turned to a black calx, on mixing three parts thereof with one of melted ſulphur. And if the parts of the ſulphur be ſtirred among the quickſilver; they coat over the ſurfaces of the ſubtle particles of the quickſilver. If therefore theſe involving particles of ſulphur are fixed and hardened by the cold; a matter ariſes which may be rubbed.

CHAP. II.

Of the Cauſe of the Fluidity of QUICKSILVER.

§. 231. AS quickſilver contracts into a ſtill narrower ſpace, the greater the degree of cold to which it is expoſed; ſo from this we may perceive, that it owes its fluidity to the fire, lodged between its particles, and ever continuing to put it in motion.

§. 232. But as it remains fluid in a degree of cold, in which ſpirit of wine has froze; ſo the query is, how a degree of fire ſo weak, which may happen ſtill to remain in ſo violent a degree of cold, is capable of ſeparating the particles of quickſilver aſunder, and maintaining them in a conſtant degree of motion? It might almoſt be doubted, whether this ſo weak a fire could have ſuch an effect, as quickſilver is 14 times heavier and denſer than water. But in this caſe we are to conſider the uncommon ſubtlety of the particles of quickſilver. A cubick inch of quickſilver contains, indeed, 14 times the quantiy of matter, that a cubick inch of water does. But poſſibly a very ſmall particle of quickſilver, which no longer conſiſts of quickſilver particles, is much ſmaller and lighter than a very ſmall particle of water. Suppoſe the weight of a very ſmall quickſilver particle were only the hundredth part of the weight of a very ſmall water particle; in order to move ſuch a quickſilver particle, the hundredth part only of the power of a particle of fire would be neceſſary, by which one particle of water may be ſeparated from another.

PART VI.

Of the ELECTRICAL MATTER.

CHAP. I.

Of ELECTRICITY.

§. 233. ELECTRUM or amber rubbed, manifeſts a degree of light and of motion; by which, light and contiguous bodies, as leaf-gold, are attracted to it, and repelled from it. Theſe phænomena, or appearances, in the firſt and proper ſignification are called *electricity.* But they may be alſo produced in other matters, as ſulphur, ſealing-wax, porcelane and glaſs by rubbing; and communicated to other matters, as water and metals. For want of a word, by which to expreſs theſe phænomena, the term electricity, has had a general ſignification allotted it. And thus by electricity we in general mean that ſtate, in which a light together with a motion, by which light bodies may be attracted and repelled, appears in a body; as in rubbed electrum or amber. The body itſelf, in this ſtate, is ſaid to be *electrified.*

In the experiments and diſſertations of the philoſophical ſociety in *Dantzick*, P. I. M. *Daniel Gralath* in 1747, gave a hiſtory of electricity. At *Paris* in 1752, was publiſhed *une Hiſtoire generale et particuliere de l'Electricité* in three parts. The experiments I myſelf made, I deſcribed in three writings; the firſt publiſhed in 1744; the ſecond in 1745, and the third in 1746. The firſt entitled, *Reflections on the properties, effects and cauſes of Electricity.* The ſecond, *The properties of the electrical matter, and electrical fire.* And the third, *The intenſity of the electrical force of water in glaſs veſſels, diſcovered by* Muſchenbroeck'*s experiment.* In quoting theſe writings, I ſhall denote the firſt by the letter E; the ſecond by F; and the third by G.

§. 234. *Electricity* in ſo far as it is excited in a body by rubbing, is called the *original* and the *proper*; and the body called *electrical* in and of itſelf. But in ſo far as it ariſes in a body, without rubbing, by the electricity of another electrified body, it is called the *communicated* and the *propagated electricity.* But this laſt in order to become obſervable, the body to which it is to be communicated, muſt reſt on a matter of itſelf electrical; of which kind are glaſs, ſulphur, ſilk and roſin, E. §. 28—31.

By the rubbing, the parts of a body, of itſelf electrical, are either ſeparated aſunder; as when for inſtance, we ſtamp or grate ſulphur G, p. 151; or, remain unſeparated; as in the caſe of glaſs and porcelane. In all which we are to conſider partly the *reciprocal motion* E, §. 6. *ſeqq.* F, §. 39. 48. partly the *continued motion* F, §. 41. 47. The machine, which I at firſt uſed with much commodiouſneſs, ordered in the manner of a Turner's bench, in which a hollow glaſs was turned, and rubbed on a leather cuſhion, I deſcribed in the hiſtorical part of the writing E, Chap. II. The experiments I made therewith in 1743, in the preſence of the young princes of *Saxony*, *Frederick Chriſtian*, and *Xaverius*, were ſeen with ſo much pleaſure by both, that electricity came to be in great vogue and requeſt. I afterwards found, that the electrical force might be excited with a greater degree of intenſeneſs, on turning a hollow, and horizontally hanging glaſs-globe, by means of a wheel, and laying on the globe, in the act of turning, a hand naturally dry. Such a machine profeſſor *Hauſen* had uſed with much advantage, before I had thought of the turning-machine juſt mentioned. The whole apparatus may be ſeen at the beginning of his diſſertation, publiſhed at *Leipſick* in 1743 by profeſſor *Gottſched*, under the following title, *Novi profectus in hiſtoria Electricitatis*. In order to heighten the electricity, I in 1745 cauſed to be made two peculiar machines,

chines, which I deſcribed in the hiſtorical part of the writing, F. c. 7. In the one, eight hollow glaſſes, with their leather cuſhions, may be worked at once by a ſingle perſon by means of a leaver. But here too, as in the caſe of the ſimple turning-machine, this inconvenience offers, *viz.* that the glaſſes by the rubbing on the cuſhions, turn very ſoon too hot, whereby the electricity loſes of its firſt degree of intenſeneſs. In the other machine, where, by means of a ſingle wheel, four globes are turned at once, and electrified by two perſons applying their hands, the electricity may be kept up a long time to an equal pitch of intenſeneſs, when the turning is continued; ſo the applying the hands be ordered in ſuch a manner, as that the globes remain unheated. With this machine in 1746 I repeated *Muſchenbroeck*'s experiment. Mr. *Watſon*, a fellow of the Royal Society of *London*, in a treatiſe tranſlated into *French* in 1748, under the title, *Experiences & obſervations pour ſervir a l'explication de la nature & des proprietés de l'electricité*, gives a deſcription of a new machine, where, by means of a wheel ſeveral glaſs globes, that rub on leather cuſhions, ſtuffed with hair, are worked at once. Inſtead of four globes, each of which is eight *Paris* inches in diameter, I uſed a ſingle globe, in diameter 17 *Paris* inches, for electrifying. But, on account of the ſize of the globe, two perſons in like manner are neceſſary to lay their hands on it, in order ſufficiently to excite its electrical force. The wheel too muſt be turned by two men, whether you electrify with the large globe, or with the four. In order thus to be able to carry on the experiments with leſs expence, I generally uſe a machine, in which the wheel is turned by a ſingle perſon, and in which two globes hang, each between eight and nine inches in diameter, on which, when turned round, one perſon lays his hands.

§. 235. Electricity may be excited as well in air as in vacuo, and forces through glaſs, ſealing-wax and pitch out of vacuum into the air, and out of *this* again into *that*. The deſcription of the machines, with which I at firſt electrified in vacuo, is contained in the writing F, Chap. VIII. of the hiſtorical part. I afterwards uſed for theſe experiments the rotatory machine, deſcribed by *Graveſande* in his *Elementa Phyſices*, §. 567, and by the abbé *Nollet* in his *Eſſai ſur l'electricité des corps*, p. 31, 32. and in his *Leçons de Phyſ.* T. III. Leç. X. Experiment XIII. The veſſel, which is ſet over the electrifying machine on the plate of the air-pump, I cauſed to be made of copper, on account of the ſhaking ariſing by the turning. On the ſide of the veſſel CD, fig. 7. Plate XIV. is an aperture with a ſcrew-nut; into which a ſcrew is introduced, with a cemented ſmall glaſs tube; through which goes a metal wire EF, faſtened with cement, at whoſe internal end F hang ſilver threads, which reach to the glaſs GH, which may be rubbed on a cuſhion in vacuo. If this glaſs be moved by means of the ſpindle IK and of a wheel, and rubbed ſufficiently at the cuſhion; it ſo communicates the electricity to the metal wire, that leaf-gold, held under the external end of the wire, is put into friſking motions, and out of the wire ſparks come forth, on approaching a finger or metal to it.

§. 236. If two bodies are electrified to an equal degree, neither will be attracted by either. If the one is eaſily moveable, it removes from the other. And if both are ſuch; both of them remove from each other, F. §. 1, 2, 3.

§. 237. From the angles, and points of electrified bodies luminous rays ſtream forth in diverging lines, E. §. 56. F. §. 57. But if the electrical matters touch two equally ſtrong electrified points, no luminous rays appear, F. §. 5.

§. 238. If between an electrical and an unelectrical body the electrical light is ſo ſtrong, as to form a cylinder, which vaniſhes with a crackling; it is called an *electrical ſpark*, E. §. 63. 69, 70, 71. F. §. 14. which can ſet on fire all fluid matters, ſuſceptible of taking fire from flame; as ſpirit of wine, and the glowing wick of an extinguiſhed wax-light, E. §. 75—79. Alſo the electrical rays ariſing in vacuo have a kindling force, which appears on the electricity going out of it into air. For, letting a ſpark ſtrike on the metal pin AB at A, fig. 8. Plate XIV. and holding at the ſame time at the pin BC under C ſpirit of wine in a ſpoon, it will be kindled by a ſpark at C.

§. 239. The electricity is ever ſtronger, the greater the maſs and matter of an electrified body; the more electrifying tubes and globes act thereon, and the leſs the matter whereon an electrified body reſts, takes the electricity, F. §. 43. 46. In particular, the electricity is heightened, if a body, ſuſceptible of receiving it by communication, is lodged in a veſſel of glaſs, or of the glaſs kind, filled with water, or a matter, ſuſceptible in like manner of being electrified. If a perſon with the one hand holds a glaſs flaſk filled with water, in which a metal wire lodges, that is electrified, and approaches one finger of the other hand to this wire, the darting electrical ſpark cauſes in the hand, and in other parts of the body, a violent ſhaking or ſhock. This experiment is called *Muſchenbroeck*'s; as having been firſt attempted, and made publick by profeſſor *Muſchenbroeck* in the year 1746, G. §. 1. How to order this experiment, and be ſafe againſt its effect; and how, notwithſtanding, to obſerve its force, I have circumſtantially ſhewn in the hiſtorical part of the writing G. c. 2, 3, 4, 5 and 6.

With theſe ſparks, excited by *Muſchenbroeck*'s experiment, I have this year 1754 excited two unexpected effects. On the 8th of *January* I ſtrewed ſeeds of lycopodium to about a quarter of an ounce on a plate, and let off an electrical ray on them, after ſufficiently electrifying water, mixed up with ſaltpetre in a number of large flaſks. For the electrifying I uſed the machine with two glaſs globes, and turned the wheel ſeveral hundred times round. Over the ſeeds I conveyed a braſs ball an inch in diameter, which had received the electricity from the water-flaſks, by means of a chain, which I held with a ſilken ſtring. So ſoon as the ball was ſo near the ſeeds, that between it and the plate a ſpark might ariſe, an electrical ray burſt forth with a great ſnap, and ſet the ſeeds under the ball in a high mounting flame. I ſtrewed again the like ſeeds on the plate, and laid flax over them, which at its ends I faſtened with wax to the plate. I cauſed again the electrical force to be excited, till arrived to a ſufficient degree of intenſity; and I conveyed the ſaid ball over the flax and ſeeds. The electrical ray burſting forth ſet fire to the ſeed, ſo that by its flame the flax catched fire all over. On the 13th of *January* I laid between one and two grains of aurum fulminans on the plate, and let off an electrical flaſh, of the intenſeneſs I now mentioned, on the aurum fulminans; and it was ſo reſolved by the flaſh, as to cauſe a loud crack, and leave behind a mounting fume. I preſſed wax round the aurum fulminans on the plate, covered over with a ſmall circle of parchment, and ſecured again with wax on the rim, ſo that the aurum fulminans was as it were incloſed. So ſoon as the electrical flaſh went through the parchment, the action of the aurum fulminans was ſo ſtrong, as to tear the parchment in ſmall bits, and ſcatter them up and down.

CHAP. II.

Of the Properties of the Electrical Matter.

§. 240. THE electrical matter is proper to the bodies, in which electricity manifeſts itſelf; that is, they have it from their origin, and it continues united with them, ſo long as they laſt. For, ſo ſoon and ſo long, as a body, which bears being electrified by rubbing, continues capable of being rubbed, the original electricity may be excited in it. In like manner it may be given to a body, which admits the electricity to be communicated to it, ſo long as it continues a body.

As bodies, which are of themſelves electrical, are rubbed with matters, which cannot be electrified by rubbing; it might be ſurmiſed, that perhaps the bodies, which are of themſelves electrical, contained no electrical matter, but by rubbing only were made capable of admitting into them the electrical matter from the bodies, with which they were rubbed. But this is only mere ſurmiſe. If you put powdered glaſs into a glaſs veſſel, with a braſs wire in it, and communicate the electricity thereto: The electricity will be as intenſe as when water is in the glaſs.

So little reaſon as we have to hold the electrical matter, which manifeſts itſelf in bodies, when rubbed, for a bare efflux, ariſing only from the rubbing things; ſo little are we to conſider the electrick matter in the bodies, to which the electricity is communicated, as an efflux, barely proceeding from a body of itſelf electrical and rubbed. For, if a glaſs tube or globe is electrified by rubbing, and you let a metal chain, which hangs at ſilken ſtrings, be touched by the tube or globe: The whole chain, the moment it is touched, is electrified, though with many thouſand times more ſurface and maſs than tube and globe. In the moment, that the one end of the chain is touched by the tube or globe, an electrical ſpark flies out of the other, on a finger, or a metal, at a due diſtance from that end. The electricity ariſing in a metal, if touched by a rubbed glaſs globe, is far ſtronger than the electricity of the globe itſelf. And the greater the maſs of the metal, the ſtronger electrical ſparks fly from it. In particular, the electrical power increaſes, if water is electrified in glaſs veſſels. All this is a confirmation, that the bodies, which admit being electrified by the touch of rubbed bodies, have not their electrical matter from the rubbed bodies.

§. 241. The electrical matter encompaſſes and ſaturates the bodies, which admit electrifying, as a conſtantly fluid and cohering ſubſtance. For, a body which bears imparting electricity to it, when reſting on a matter of itſelf electrick, how great or long ſoever; yet it bears to have its whole ſurface electrified in a moment by a ſingle ſpark. You need only hold a ſmall piece of metal at a ſilken thread, ſo it reſts on a body, to which the electricity is communicated, and then with the thread draw it off the body, and bring it to a metal chain, that hangs at ſilken ſtrings; and it will be inſtantly electrified from one end to the other. Now each part of ſuch a body, how ſmall ſoever, may be electrified, ed. So that all the parts, into which a body is reſolvable, are encompaſſed with electrical matter. But the parts of a body are ſo combined together, that there are every where between them interſtices, in which a ſubtle matter may lodge. From this it is evident, that a body, which admits imparting electricity to it, is ſated throughout with electrical matter, as a kind of fluid ſubſtance. And this may be affirmed even of the bodies, that bear electrifying by rubbing. For, if an exhauſted glaſs globe be rubbed externally, a light appears on its internal ſurface. In like manner there ariſe flaſhes, which move up and down in an exhauſted globe or tube, when touched by an electrified metal. On rubbing the internal ſurface of a cloſe glaſs or porcelane veſſel, leaf-gold, lying at a certain diſtance from the external ſurface, is put into friſking motions, F. §. 21.

§. 242. The electrical matter conſiſts of parts, in which light is in various manners refracted and reflected. On viewing an electrical ſpark, produced in air, through one of *Marſhal's* magnifiers, it appears like a pure azure ſtream of the pureſt fire. But ſtream the electrical matter from a metal wire or pin in vacuo, a variety of colours appear; eſpecially, when the ſpace between the wire AB and BC, fig. 8. Plate XIV. under the exhauſted bell, is only two or three inches long, and externally at BC a chain lies. The colours exhibit themſelves to ſight, without needing to view the matter, ſtreaming in vacuo, through a priſm. From this it is clear, that the parts of the electrical matter muſt differ from each other in contexture.

§. 243. As the electrical matter fires ſpirits of wine and ſeeds of lycopodium, and in the manner of a heated matter reſolves aurum fulminans, §. 238. *ſeq.* it appears to hold fire. Perfectly certain it is not. For, as the parts of the electrical matter are highly ſubtle, and act with great velocity; they may hereby probably put the fire, included in inflammable matters, into motion, without being themſelves a fire.

If fire be found in the electrical matter, it may in reſpect to the other matters be of inconſiderable power. In all appearance, an electrical ſpark ſhould fire ſeeds of lycopodium, without requiring to be excited in *Muſchenbroeck*'s manner. A flame never ſo ſmall fires them. Whereas in *Muſchenbroeck*'s experiment the electrical force muſt be heightened by much water, mixed with ſaltpetre, for the burſting electrical flaſh to fire the ſeeds of lycopodium, ſo as to mount up in a flame. The intenſity of ſuch a ſpark I deſcribed in 1753, in a *Programma de avertendi fulminis artificio ex doctrina electricitatis*, p. 10, 11. Were ſuch a flaſh for the greateſt part only fire; there could be no reaſon, why it ſhould not fire gunpowder, eſpecially as its effect is ſo quick and intenſe.

§. 244. The electrical matter is elaſtick, or has a conatus to expand itſelf. For, from the angles and points of electrified bodies luminous rays proceed in diverging lines, E. §. 56. If an unelectrified body approaches theſe rays, it in like manner emits ſuch rays, which unite with the other, F. §. 10. In vacuo ſuch cones of light, which ſtream againſt each other from an electrified and unelectrified body, appear very diſtinctly, on making the experiment in the dark, F. §. 57. If we view through a magnifying glaſs the ſurfaces of two metals, ſo diſtant aſunder in the open air, that the electrical matters ſtreaming from them, cannot attain the denſity of a ſpark; we obſerve on both ſurfaces luminous globules, that appear to play upon them. If at a ſtrong electrified metal the flame of a candle ſtands; it will be blown along as by a wind proceeding from the metal. And this ariſes, ſtand the flame at the metal where it will. And bringing any part of an unelectrified body within a certain diſtance of one electrified; you may obſerve the electrical matter ſtreaming forth from it. The electrical matter therefore of a body ſeeks to exert itſelf every way round its ſurface.

§. 245. And thus a body is electrified, ſo an electrical matter is put into motion, ſo as to expand itſelf, happen it either with or without rubbing.

§. 246. In the electrical matter of a body, which bears being electrified without rubbing, this motion ariſes, ſo ſoon as it is touched by an expanding electrical matter. But if a body may not be electrified otherwiſe than by rubbing, its electrical matter will not in any remarkable manner be reſolved and expanded by the bare contact of an expanſive electrical matter. If this happened, the electricity would be conſiderable in no body, that may be electrified without rubbing. Were, for inſtance, the electrical matter of ſilken ſtrings, at which a metal tube or chain hangs, on communicating the electricity thereto, reſolved in an equal degree by the bare touch of their reſolved electrical matter; the electrical matter of the bodies, at which the ſilken ſtrings are faſtened, would be put into this very motion. But thus it would be juſt the ſame thing, as if a metal tube or chain, hanging at ſilken ſtrings, were touched by a perſon, not ſtanding on a matter, which we call of itſelf electrical, §. 234. Now as by touch of ſuch a perſon, tube and chain cannot be electrified; or having been before electrified, loſe the electricity; ſo they would never gain a degree of electricity, did the electrical matter of the ſilk, the glaſs, the pitch and other bodies of this ſpecies, reſolve in equal meaſure by bare contact of a reſolved electrical matter. So ſoon as a metal, hanging at ſilk which is electrified, touches melted pitch, its electricity vaniſhes inſtantly, F. p. 110. We may eaſily imagine that the electrical matter of the pitch is as ſtrongly reſolved by the melting, as the electrical matter of the metal by touching a reſolved electrical matter.

§. 247. The electrical matter of a body, which may be electrified no otherwiſe than by rubbing, has therefore either among its parts, or with its body a far ſtronger degree of coheſion than the electrical matter of a body, which may be electrified without rubbing.

CHAP. III.

How the electrical Effects ariſe.

§. 248. SO ſoon as the electrical matter of a body expands itſelf; it has a conatus to ſnatch the body along with it. For, this matter has a certain degree of coheſion therewith.

§. 249. If therefore the electrical matter expands itſelf on one ſide of the body ſtronger than on the other; and if this elaſticity is more intenſe than the gravity of the body; it will be ſnatched along by its electrical matter towards the place, it ſtreams out the moſt intenſely to.

§. 250. In this manner ariſes the attraction of an eaſily moveable body, when ſo nigh a body not eaſily moveable, that both electrical matters mutually touch, ſo they expand themſelves. And let the electrical matter firſt expand at the immoveable body: That moment the electrical matter of the eaſily moveable body, by virtue of its elaſticity, ſtreams againſt it, §. 244. and thus ſnatches it along with it to the immoveable body. And this very thing muſt happen to the eaſily moveable body, ſo its electrical matter firſt expands itſelf. For, ſo ſoon as this happens, the electrical matter of the moveable body ſtreams againſt it, §. 244. and is hereby rarified. And thus the electrical matter of the eaſily moveable body expands itſelf towards the part, from which the electrical matter of the immoveable body ſtreams againſt it, ſtronger than towards another part; and thus again hurries along with it the eaſily moveable body towards the immoveable.

§. 251. And if thus the gravity of both bodies is weaker than the force, with which their electrical matter expands; both bodies will move towards each other. And thus it will appear, as if they attracted each other alternately.

§. 252. So the electrical matter ſtreams out of one body, the other, againſt which it ſtreams forth, acquires an impulſe. If therefore both bodies are eaſily moveable, and ſtream their electrical matters againſt each other with an equal degree of intenſeneſs; the electrical matter of the one forces the other out of its place. So that both bodies remove from each other, and continue in that ſtate, ſo long as the equally intenſe efflux of their electrical matters are propagated againſt each other. If leaf-gold rolled up together, hangs at a ſilken thread near a metal tube, reſting on ſilken ſtrings, to which the electricity is communicated; it will be driven firſt to the tube, and then again from it. The firſt happens, as the electrical matter of the unelectrified leaf-gold is in the firſt inſtant, in which the metal tube acquires the electricity, denſer than the electrical matter of the electrified tube. For, thus the denſer matter of the leaf-gold expands itſelf towards the tube, at which the electrical matter is rarer; and thus hurries off along with it the leaf-gold to the tube. But ſo ſoon as it touches the tube, the electrical matter of this laſt will be as intenſely expanded and rarified, as the electrical matter of the tube reſting on the ſilken ſtrings; as the leaf-gold hangs at a ſilken thread, and therefore acquires as little acceſſion of new electrical matter from the air as the metal tube. So that the electrical matters of the leaf-gold and tube ſtream with equal intenſeneſs againſt each other. Now ſo the gravity of the leaf-gold be weaker than the elaſticity of the electrical matter ſtreaming from the tube; the leaf-gold will be driven ſo far, as the violence of the ſtream can carry it. From this very reaſon a whole number of grated bits of leaf-gold, lying ſtrewed on a ſurface ſome ells in length, riſes at once therefrom into the air, ſo ſoon as the electricity is communicated to the ſurface.

§. 253. The luminous lines, in which the electrical matter ſtreams forth, conſiſt of ſmall particles. Each exhibits a luminous point. Theſe points are ſeparated from each other by ſmall interſtices. One point follows another with a great degree of quickneſs. They proceed in oppoſition to each other from the electrified and unelectrified body, and from one body to another, F. §. 31. By theſe motions the parts of the light or æther between both bodies are puſhed and preſſed together. As the electrical points are ſeparated from each other, and each moves from one place to another with the higheſt degree of quickneſs; the compreſſed particles of light again expand themſelves. And as thus the particles of light are now denſer, again rarer, from the electrical particles going in a conſtant alternation from the electrified body towards the unelectrified, and from *this* again to *that*, it is thus the light ariſes, §. 211. 215.

§. 254. If two bodies are electrified equally ſtrong, their electrical matters are rarified and expanded in an equal degree, §. 245. So that they fail of the motion, by which they go alternately from one to the other. And in this ſtate they can thus excite no light.

§. 255. If the electrical matters have ſo expanded themſelves from the electrified and unelectrified body, and ſo collected themſelves in the ſpace between them, that the electrical matter ſtill remaining at the ſurfaces of both bodies is rarer; ſo by virtue of the elaſticity, §. 244. one part of the collected matter muſt go towards the electrified, and one towards the unelectrified body. In this manner the electrical ſpark divides itſelf and vaniſhes.

§. 256. How in the time it ſeparates, a crackling, or alſo, on exciting the electrical force in *Muſchenbroeck*'s manner, a ſnap ariſes; we ſhall explain under the doctrine of ſound.

§. 257. The ſtronger the electrical matter of a body reſting on ſilk or glaſs is reſolved and expanded; the more plentifully may the electrical matter of an unelectrified body force by its elaſticity againſt the electrified. This happens, on electrifying water in glaſs veſſels, which again ſtand in water. For, though glaſs ranks among bodies, which may be electrified by rubbing; yet its electrical matter is alſo in ſome meaſure reſolved by the electricity of the water ſtanding in the glaſs flaſk. Experience teaches this, from electrical motions being perceived on the ſkin, and a whizzing being heard, on holding a hand towards a glaſs flaſk, in which the water has been ſtrongly electrified. If therefore ſuch a flaſk is encompaſſed with water and metals; the electrical matter forces plentifully out of theſe unelectrified bodies into the glaſs of the flaſk, and conſequently into the matter contained therein. And if thus you go on more and more to reſolve the electrical matter of the water in the flaſk by means of a glaſs globe rubbed by turning; this encreaſed electrical matter expands with ſtill greater violence. And thus if a perſon, that with the one hand touches the veſſel, in which the glaſs flaſk ſtands, approaches the wire ſtuck therein with a finger of the other hand; there muſt needs ariſe a ſtrong electrical ſtream between the finger and the wire.

PART VII.

Of the MAGNETICAL MATTER.

CHAP. I.

Of the Diviſion of the Phænomena of the MAGNET.

§. 258. THE magnet is a ſtone, which as well attracts iron, as it is again attracted by iron, and in contact coheres therewith. This effect, indeed, manifeſts itſelf all over the magnet; but with peculiar intenſeneſs at ſome points only, as at which iron-filings adhere in greateſt plenty. If the magnet hangs free at a thread, it winds and turns, till the one point is directed towards north, and the other towards ſouth. And hence theſe points are called its *poles*. The right line, which we may conceive drawn through theſe poles, is called its axis; and the plane, by which the axis is cut at right angles, its *equator*; and each ſeveral line, that may be drawn on its ſurface from one pole to the other, a *meridian*.

§. 259. If a magnet is armed, or enaſed, its effect proves ſtronger. The arming is performed as follows: The magnet is ground down at both the poles, which ſtand mutually oppoſite; and on the ſides at which the poles are, ſo laid with plates of ſoft iron, as to form, as much as may be, right angles with the axis of the magnet. To each plate is a ſmooth cubical foot, called the *foot of armature*, as alſo the *artificial pole*; as the natural poles manifeſt their effect by theſe.

§. 260. So ſoon as iron is rubbed on a magnet, it is fitted to act in the manner of the magnet itſelf: And hence aroſe the magnetical needle. It is prepared of ſteel, is oblong, ſlender and narrow, with a ſmall braſs hood, excavated of a conical form. In the point of this excavation it is divided into two equally heavy halves, and reſts on a metal point. In order to communicate the magnetick force thereto, it is laid on a wooden table, and a pole of an armed magnet ſet on its middle, and ſlowly conveyed on it quite to its point. This is repeated a number of times. But you muſt not carry back the magnet on this half; as the force ariſen again ceaſes thereby. You therefore bring again the magnet on the middle of the needle by taking a round about way, ſetting thereon the ſame pole with which you touched at firſt, and carrying it again along the touched half to the end. If the carried pole of the magnet is the ſouth, the touched half of the needle turns north. And in order to make the other half magnetical alſo, you touch it with the north pole of the magnet, carrying it in like manner from the middle to the other end.

§. 261. The phænomena, by which the magnet aſtoniſhes its beholders, conſiſt partly in its direction, and that of the magnetick needle towards a certain point of the earth and heavens; partly, in attracting, and repelling, and partly in communicating the magnetick virtue. All which manifeſt themſelves by manifold circumſtances, as the remarkable experiments ſhew, publiſhed by *Muſchenbroeck* in his long diſſertation *de Magnete*, and by baron *Wolfius* in his *Experiments*, P. III. c. 5.

CHAP. II.

Of the Magnetick Matter.

§. 262. AT the poles of a magnet is an inviſible matter, which is in conſtant motion. For, if at a certain diſtance from an armed magnet two iron keys are ſo held, that one ſtands with its ring over the ring of the other and touches it; and ſo the under key either remains hanging at the upper, or at leaſt as to the touch manifeſts a conatus to cohere. In particlar the coheſion ſhews itſelf, when the feet of the magnet have an horizontal poſition, and the keys are in the manner of fig. 5. Plate V. ſo held together, that the ring of the under is raiſed ſomewhat over the under foot of the magnet. If the upper key hangs at the one end of a balance, and at the other a body of equal weight; it ſinks down with the arm, on approaching thereto the under key. None of which appearances would be obſervable, were there no matter about the magnet, that acted on the keys. For, the magnet is touched by them in no part. Should this coheſion ariſe without the force of a certain matter, the keys muſt unite in the neighbourhood of any other body. This inviſible matter, which is about the magnet, may be called the *magnetical*.

On throwing iron filings on paper, and drawing along a magnet under the paper, different vortices or circles appear. This method *De la Hire* uſed, in order to exhibit the effects of the magnet. In *Muſchenbroeck*'s diſſertation on the magnet, you find Plate III and IV ſeven figures, that repreſent the courſe of the magnetick ſtream according to various circumſtances. Theſe experiences gave occaſion to M. *Bazin*, member of the academy of *Belles Lettres* at *Rochelle*, and correſpondent of the royal academy at *Paris*, by new experiments to bring the magnetick matter to exhibit to our eyes its courſe, and all its different windings by certain ſigns, that were plain and diſtinguiſhable. His attempt was crowned with the deſired ſucceſs. He cauſed to be made a number of ſmall ſteel plates of regular figures; ſome of which were a half, others a whole line, and others again two lines thick. Theſe plates, made magnetical, he laid on the table, gave them what poſition he would, laid over them a piece of white paper, and ſtrewed thereon fine ſteel or iron filings. And in order to ſtrew it more regularly, he let them fall through a fine ſilken ſearce. So ſoon as this duſt falls, we obſerve, how, as it were naturally, it diſpoſes itſelf in a certain order. But in order to take the form, which the magnetick ſtream may give it, duly perfect, you ſtrike ſoftly with a key below on the table. Theſe ſmall blows cauſe the light particles of iron to ſpring up, and mount in the air, in which they are the eaſier taken and puſhed by the magnetick ſtream, and laid in a ſituation adapted to its effect. The deſcription and repreſentation of the magnetick ſtreams, which M. *Bazin* publiſhed, may be ſeen in the *Hamburgh* Magazine, T. 12.

§. 263. The magnetick matter is fluid, and more ſubtle than air. For a magnet may be either ſhut up in a veſſel of metal, as for inſtance, braſs, which is run cloſe, or hung under a glaſs bell, and the ſpace under it exhauſted of air; and in both caſes an untouched needle of iron moves towards the magnet when hanging at a thread externally near the veſſel and bell. From this it appears, that glaſs and metal are penetrated by the magnetick matter. And thus it is finer or more ſubtle than air. By the fixt or more ſolid parts of the metal and glaſs, which of themſelves are impenetrable, the parts of the magnetick matter are ſeparated aſunder. Whereas by the ſmall interſtices between the ſolid parts, the parts of the magnetick matter unite together. In theſe properties conſiſts the fluidity, §. 49.

As the effect of the magnet ariſes as ſtrong and as quick through metal and braſs, as when the ſpace between the needle and magnet is filled with air only; it appears impoſſible to ſome naturaliſts, that the magnet ſhould be encompaſſed with a matter, conſiſting of ſuch fine and ſubtle parts. This appearance of impoſſibility is heightened by the two following experiments: You ſet a touched needle under a glaſs bell, which you exhauſt of air. Without the bell you place a magnet, by whoſe action the needle is brought out of its meridian. Between it and the bell you fire ſpirits of wine in a braſs veſſel. Be its fire never ſo ſtrong, the needle remains unmoved in the poſition which at firſt it gained by the preſence of the magnet. In like manner it retains its poſition, whether you produce a wind either by a pair of bellows, or by compreſſed air, either from a copper ſphere, or wind-gun, between the bell and the magnet.

It is therefore concluded, that neither the ſtrength of wind, nor the violence of fire, nor the denſity of bodies obſtructs the force, with which the magnet acts on iron. And thus the magnet cannot exert its effect by means of any ſubtle matter. But if this conſequence be admitted, neither can we aſcribe any electrical matter to electrified bodies. If a bar of iron hangs at ſilken ſtrings, and is electrified, its electricity ſhews itſelf even in the ſtrongeſt wind. Let two iron hooks hang down at ſilken ſtrings, in which place a glowing iron bar, and communicate the electricity to it; and the bar in the ſtrongeſt glow will yield as well electrical ſparks, as alſo put into a friſking motion underlaid grains of ſand and leaf-gold. Let a candleſtick, on which a candle burns, be electrified, and place a body on ſilken ſtrings at the diſtance of an ell and more from it, and yet the body will take the electricity. Let the ſpace under a glaſs bell be never ſo well exhauſted, leaf-gold, lying on a ſmall ſtand under it, begin inſtantly to friſk, ſo ſoon as an electrified body approaches from without the bell, without touching it. Neither the motion of air, nor the ſtrength of fire, nor the denſity of glaſs obſtructs therefore the force, with which an electrified body acts on one unelectrified. But how ſhould it thence follow, that an electrified body exerts its effect by no ſubtle matter?

§. 264. The magnetick matter, which moves at the pole of a magnet, goes not to the cognominal pole, or of the ſame name, of the other. For, if a magnet hanging at the arm of a balance be in æquilibrio with a body hanging at the other arm; it riſes up, ſo ſoon as a pole of the ſame name of another magnet is brought under one of its poles, without the poles touching each other. And hence the poles of the ſame name are called the *jarring* and *contrary* poles. A needle, which hangs ſtraight down at a pole, removes from it on the approach of a pole of the ſame name, and raiſes itſelf, remaining in this oblique poſition, ſo long as the cognominal pole is left near it.

§. 265. So that each magnet is provided with magnetick matter, ſtreaming from one pole to the other. For, on laying and preſſing an iron needle untouched on the equator of a magnet;

it turns, the moment you remove the finger, into the meridian, and remains lying therein. And this very thing happens, on laying on the magnet a ſmooth plate of braſs or ſilver, and on that the needle.

§. 266. But it ſtreams out of one pole, and in into the other. For, if a magnet hangs in æquilibrio at a balance, it ſinks down with the arm, at which it hangs, on bringing an immoveable magnet ſo under it, that the uncognominal poles or poles of different names, ſhall ſtand oppoſite to each other; and at length it unites with the immoveable magnet, if the ſpace between both is not quite too great. If the immoveable magnet is hung at the arm, and that, before moveable, removed, and held under the appended one with the pole of a different name; the appended in like manner ſinks down and unites with the under, ſo the intermediate ſpace is no hindrance. And hence the incognominal poles are called the *agreeing* and *friendly*. Now if the matters ſtreamed from both incognominal poles in ſuch a manner againſt each other, as that neither the matter at the north pole of the one could penetrate into the ſouth pole of the other; nor the matter at the ſouth pole of the one into the north pole of the other; the incognominal poles muſt as well remove from each other, juſt as the cognominal do, §. 264. In like manner neither might approach either, if from neither the matter ſtreamed forth.

CHAP. III.

The Phænomena of the MAGNET explained.

§. 267. AS the magnetick matter puts iron and load-ſtone only in motion, whereas all other bodies known to us force through unhindered; the void and inviſible interſtices in the iron and load-ſtone muſt be ſo ordered, that the magnetick matter has ſome obſtructions to remove in the paſſage. We may with profeſſor *Euler* in his *Nova theoria Magnetis*, repreſent to ourſelves, as if in the magnet or iron on the ſides, between which there is ſuch a cavity, certain tender and flexible particles projecting therein, and touching each other at an oblique angle. A row of ſuch cavities, following each other in a line, and over-run with ſuch particles or ramuli, profeſſor *Euler* with *Deſcartes*, who in his *Principia Philoſophiæ*, P. IV. §. 133. *ſeqq.* paved the way for an intelligible explication of the magnetick phænomena, calls a *magnetick meatus* or *paſſage*. A repreſentation of ſuch a paſſage, fig. 6. Plate V. gives. From A to B the magnetick matter indeed, has, ſome force to apply, for the tender ramuli or filaments to be forced ſideways; but yet can force quite through. On the contrary, from B to A their paſſage is blocked up, as the filaments, by the conatus of the magnetick matter, are preſſed againſt each other. This diſpoſition of the magnetick paſſages is far more inartificial or ſimple than the configuration, which *Deſcartes* allots them; as he repreſents them as ſo many ſpirals. Alſo according to *Euler*'s diſpoſition there is no reaſon with *Deſcartes* to imagine the particles of the magnetick matter as ſo many ſmall ſpirals.

§. 268. Let therefore two poles of unlike names, as B and A, be brought together, and put the caſe, that the magnetick matter ſtreams forth out of B. Thus it may force into the incognominal pole A, and move quite through to B. But ſuppoſe B A hangs at a balance, fig. 7. Plate V. and A B lies immoveable on a ſmall ſtand under B A. Now as the magnetick matter from B ſtreams into A, A therefore will deſcend to B, and unite with B? Let B A hang at the balance, and invert A B, fig. 8. Plate V. So that the pole A, at which the matter flows in, is obverted to the cognominal pole A, at which the matter in like manner forces in. Will therefore one pole repel the other from it, as the matter ſtreams in into one pole? So that without ſide the magnets, there muſt be ſtill ſomething, which by its force can as well unite two magnets with, as alſo ſeparate them from each other, ſo the magnetick matter goes either out of one pole into the other, or from none into the other.

§. 269. As the magnet as well as the magnetick needle directs itſelf towards a certain point of the earth and heavens; there muſt be a certain matter in and above the earth, by whoſe motion the magnet and magnetick needle gain their direction. This matter may be of the ſame ſpecies with the magnetick. Only we are to enquire into the nature of its force and motion, in order to produce the ſaid direction. *Gilbert* in his firſt book *de magnete* appropriates to the earth the properties of the magnet, and therefore with the view of rendring his opinion the more diſtinct, cauſed to grind a magnet, round like a globe, and called it a *terrella*, or little earth. *Deſcartes*, therefore, who held *Gilbert* for the principal enquirer into the magnetick virtue in his time, lets his ſpiral particles of the magnetick matter ſtream out of the north-pole, quite round the earth, and in at the ſouth-pole, and through the middle of the earth out again at the north-pole: In like manner out of the ſouth-pole, and quite round the earth, and in at the north-

north-pole, and quite through the middle of the earth, out again at the ſouth-pole. Neither the magnetick paſſages, nor the magnetick particles are in his explication of one and the ſame figure. Neither the particles, which come from the north pole, can force into the paſſages, out of which the particles at the ſouth-pole ſtream forth; nor theſe laſt into the paſſages, out of which the particles at the north-pole flow forth, on account of their figure.

§. 270. Theſe thoughts profeſſor *Euler* has carried farther, but explained the whole affair in a conciſer manner. The magnetick paſſages in the earth are, according to his theory, all of one and the ſame configuration. Into the pole, from which the matter ſtreams forth, there is no influx; and no efflux from the pole, at which the matter ſtreams in. The magnetick matter in and above the earth is elaſtick. Suppoſe one magnetick pole to be at A, fig. 9. Plate V. the other at B, and the magnetick paſſages to run from A to B, and thoſe in the earth to be at firſt void of magnetick matter. The magnetick matter, which encompaſſed the earth, took its way therefore by means of its ſpring with violence into the magnetick paſſages of the earth at A. For, as the ramuli and filaments of the paſſages are ſo diſpoſed, that no magnetick matter can force into them at B; there came from

B to A nothing againſt the matter forcing in at A, which could with equal power withſtand its motion. And therefore the matter forced in muſt burſt out at B. In the burſting out it met with a ſtrong reſiſtance in the external matter; and was thus beat back in the manner the wind is, which ſtrikes on an immoveable body. In the paſſages from B to A it could not go back, partly on account of their ſtructure according to fig. 6. partly on account of the following matter. On both ſides the reſiſtance of the external magnetick matter was weaker than in the part of the eruption at B. For, as the matter forced in at A; ſo the matter, on both ſides by virtue of its elaſticity muſt expand into the ſpace, which the matter at the part at A left. And thus the matter burſting forth out of B ſhared itſelf out towards the ſides C and D, and went on in curved ſtreams to A, and there again had its influx. And thus as the preceeding matter never reſtrained the following, and the external at B always made the greateſt reſiſtance; ſo the magnetick matter muſt whirl in never ceaſing ſtreams round the earth out of one magnetick pole into the other, and ſhoot into the magnetick paſſages through the earth with a great degree of quickneſs. It is eaſy to imagine, that the external magnetick matter never remains in the ſame ſtate. There muſt, ſurely, from the nature of elaſtick matters in motion, ſome parts of the effluent matter mix therewith, and again from the external ſome particles force into the effluent, and proceed on with its vortex or eddy. The parts of this magnetick eddy *Euler* holds for the ſubtleſt ſubſtance of the æther. But whether the magnetick matter conſiſts of the ſubtleſt particles of æther or no; yet from the elaſtick force, and the vortical motion of a matter, which comes near to æther in ſubtlety, and from the deſcribed magnetick paſſages as well in the earth, as in ſingle magnets and iron, the magnetick phænomena may be explained in an eaſy, intelligible manner.

271. As the magnets, which we find on the earth, after the nature of this great magnet have magnetick paſſages, §. 267: So the magnetick matter muſt ſtream into them at one pole, and out of them at the other, and for the very ſame reaſon, from which it whirls round the earth, form a vortex about them.

§. 272. If the magnetick paſſages in a magnet run in parallel and right lines from one end to the other; the magnet is called *ſimple*, and thus has two poles only. But if the magnetick paſſages lie in any other diſpoſition, the magnet is called *compound* and *anomalous*. And ſo a magnet may have three poles; if, for inſtance, the paſſages which unite in the pole A, fig. 10.

Plate V. run in diverging poſitions to the poles B and *b*. Either of B and *b* is ſtronger than the other, if more magnetick paſſages come together in it, than in the other. As the matter, which goes through both magnets, has one and the ſame nature, and its motion in the compound is only manifold; ſo in the preſent enquiry we have principally to conſider the ſimple.

§. 273. The cauſe of the direction, when the magnet turns to a certain point of the earth, is to be ſought for partly in its magnetick paſſages, partly in the elaſtick force and motion of the magnetick and whirling matters round the earth. Imagine a ſingle magnetick paſſage in the earth's vortex to have the free poſition AB, fig. 11. Plate V. and the whirling matter to ſtream along the line AC, which forms an angle with AB. Were the magnetick matter in a ſtate of reſt, it would by virtue of its elaſticity, force into the paſſage AB, and conſequently acquire a certain degree of motion. But as without the elaſticity it already ſtreams towards AC, ſo a compound motion ariſes, whereby the paſſage is made in the diagonal AD, §. 13. As the matter in the earth's vortex conſtantly ſtreams to AC; ſo by this force and the elaſticity, wherewith the matter forces into the paſſage AD, again a compound motion in a diagonal will be produced, which forms with AC an angle ſtill leſs than the angle DAC. So that at laſt the paſſage comes into the line AC, and has thus one and the ſame direction with the magnetick matter of the earth. If the magnetick paſſage lies at firſt in the line AC, in which the magnetick matter ſtreams forth; it continues in this poſition, ſo another and greater force drive it not out.

§. 274. If the magnet is anomalous, and has more than two poles; the magnet will come into ſuch a poſition, in which the forces, acting towards different points, are in æquilibrio.

§. 275. A magnetick needle in the ſame manner as the magnet maintains a poſition towards a certain point of the earth. And thus in like manner it muſt have magnetick paſſages, which correſpond with thoſe in the magnet. We may therefore conſider the magnetick needle as a ſimple magnet; and in the enquiries made to explain the magnetick phænomena, uſe the magnetick needle inſtead of the magnet.

§. 276. If in the earth there were only two magnetick poles, diametrically oppoſite to each other; we might in general affirm, of the direction of the magnetick needle what follows. From the pole B, fig. 9. Plate V. the magnetick matter may ſtream out, and in at the pole A; and B may be the north, and A the ſouth pole; though in conſideration, that the attraction and repulſion manifeſt themſelves at both poles, it cannot be made out, whether we are to aſcribe the efflux to the north or the ſouth pole. Further, take a magnetick needle *ab*, in which the pole *a* gives inlet, and the pole *b* outlet to the magnetick matter. Be the magnetick needle therefore in the earth's magnetick vortex where it will; its abſorbing pole *a* will be directed towards the earth's magnetick north pole B, out of which the matter ſtreams forth; and the needle's ſtreaming pole *b*, towards the earth's magnetick ſouth pole A, which takes in the matter, §. 266. At both magnetick poles of the earth, therefore, the needle muſt ſtand vertical, ſo that through the poles of the needle and magnetick poles of the earth a right line might be drawn, or the line drawn through the poles of the needle might paſs through its axis. For, the matter ſtreaming forth out of *b*, will be preſſed equally ſtrong to both ſides by the magnetick matter, which encompaſſes the earth. The places C and D may be equi-diſtant from the magnetick poles B and A or 180 degrees, and thus in the magnetick æquator. The right line, which may be drawn through both theſe points, is the magnetick diameter of the earth. If therefore the needle ſtands vertical on B; the line, which from its poles *b* and *a* paſſes through the magnetick axis of the earth, forms with the diameter right angles. If the needle is in a certain diſtance from the pole B, the lines which may be drawn through it, forms with the magnetick axis an oblique angle, which is always greater, the nigher the needle is to the point C. And thus in C the line, which may be drawn through the needle, goes through the magnetick diameter of the earth. The æquator, in which are the points C and D, exhibits at the ſame time the horizon, on conſidering the magnetick pole B as the zenith. In the places C and D therefore, the needle ſtands horizontal. From the places C and D to the pole B, the needle inclines to the horizon. This angle is ever greater, the nigher the needle comes to the pole B. For, this angle of inclination of the magnetick matter increaſes with its greater proximity at the pole B to the horizon. And this very thing happens to the magnetick matter, and conſequently alſo to the needle in the places from C and D to the pole A. The horizon, in which the points C and D are, is the true horizon. As well in the north hemiſphere between C and B, as alſo in the ſouth hemiſphere between C and A, we may every where between C and B, and between C and A repreſent to ourſelves a viſible horizon. And thus on the north hemiſphere, the needle with its pole *a*, which is directed to the north pole B, is depreſſed, ſo long as it is above the magnetick æquator. But if on the ſouth hemiſphere below the æquator; it is with the pole *a* raiſed above the apparent horizon, as *b* is directed to A. All theſe directions may be plainly diſtinguiſhed on *Gilbert*'s terrella; or taking for the purpoſe an inclinatory, or inſtrument in which a magnetick needle may ſhift out of the horizontal poſition into the vertical, or out of *this* into *that*. If you bring a compaſs, or an inſtrument, in which the magnetick needle ſtands horizontal, and can only ſhift round in a circle on or above the horizon, on *Gilbert*'s earth; the following poſitions and ſhiftings appear in the magnetick needle. If *Gilberts*' earth lies with its axis on the horizon; the needle ſtands in the meridian, be the compaſs placed at the north or ſouth pole. But if it be diſtant either from the north pole towards the ſouth, or from this towards the north pole; the needle declines from the meridian. If the compaſs ſtands at the north pole B, the abſorbing pole *a* ſtands at it. But if the compaſs ſtands at the ſouth pole A, the emitting pole *b* is at this ſouth pole. If you carry the compaſs on the horizon from the north to the ſouth pole, the needle in it ſhifts round in a circle.

§. 277. Were therefore the magnet of the earth adjuſted in the manner of *Gilbert*'s earth; we might at each place eaſily judge from the declination and inclination of the magnetick needle the direction of the magnetick matter; and by a few trials and obſervations attain to the knowledge of a rule, from which the declination and inclination of the needle might be previouſly determined for each place. But the magnetick poles of the earth are not ſufficiently known to us. We ſhould accurately know their number, their places, their diſtances from the proper poles of the earth, and their forces. Further, it were to be enquired, whether a pole ever retained one and the ſame place, or ſhifted its place. The laſt may be perceived from the change, which as well the declination as alſo the inclination of the needle undergoes in one and the ſame place at different times. We ſhould therefore have a rule, according to which theſe changes happen.

§. 278. In explaining the reaſons, why two magnets attract each other alternately, when the poles of different names ſtand oppoſed to each other at a due diſtance; we are above all to conſider the manner, how a magnet by its own vortical matter may come into motion. If the magnetick matter, which ſtreams forth out of B, fig. 12. Plate V. is driven by the external magnetick matter with equal intenſeneſs on both ſides towards β, as to run on on both ſides the magnet, and flow in again on both ſides from α

into the pole A; the magnet cannot move either to B or to A, and muſt therefore continue in a ſtate of reſt. But if the matter ſtreaming forth out of B met with no reſiſtance; the magnet muſt move ſtraightway on from B. For, thus the external magnetick matter would preſs ſtronger towards A than towards B. Were the revolving matter hindred at α by the acceſſion of a ſubtle matter, ſo as not to be able to force into the pole A; the magnet muſt move ſtraitway on from A. For, the preſſure of the external matter towards B would be ſtronger than towards α. How therefore two magnets attract each other alternately, may be underſtood in the following manner. Suppoſe the axes of two magnets to lie in a right line, and the poles of different names A and *b*, fig. 13. Plate V. to be obverted to each other. The magnetick matter which goes forth out of *b*, muſt therefore ſtraitway go in at A. Partly the ſtructure of the magnetick paſſages from A to B; partly the elaſticity with which the external matter, which burſting forth out of *b*, preſſes againſt the apertures A, requires this. In theſe circumſtances neither can the ſubtle matter forcing forth out of *b* be entirely beat back to the ſides of the magnet *ba*; neither that coming out of B, and flowing at the ſides of the magnet BA towards the pole A, force into it. This matter therefore, ſtreaming out from B propagates its courſe through γ and δ on to *a*. As both the vortices of both the magnets mix together at γ and δ; ſo they withſtand the force, whereby they are other preſſed to the poles A and *b*. So that both magnets are forced together and mutually united by the external magnetick matter, which by its ſpring preſſes towards *a* and B.

The nigher the magnets are to each other, in greater quantity the matter burſting forth out of *b*, forces into A, as the pole of the other magnet, and thus in leſs quantity to the ſides to *a*, as the other pole of its own magnet. And for this very reaſon the matter ſtreaming out of B can the leſs come into the pole A. The moſt part therefore is carried on through γ and δ quite to *a*, as the pole of the other magnet. And thus the nigher the uncognominal poles of two magnets are to each other, the ſtronger muſt they be forced towards each other. If the uncognominal poles mutually touch; the whole magnetick matter, which flows out of *b*, goes immediately into A, as the pole of the other magnet; and the whole matter, which ſprings out of B, is driven to the abſorbing pole *a* of the magnet *ba*. And thus there will be a ſingle vortex, and both the magnets are to be conſidered as parts of a ſingle one.

§. 279.

§. 279. In like manner ariſes the coheſion of two keys, which §. 262. ſerved to ſhew, that at the poles of a magnet there is an inviſible matter in conſtant motion. And if this matter ſtreams through one key into the other; the keys are preſſed againſt each other by the elaſticity of the external magnetick matter, and united in the manner of two magnets.

§. 280. Cognominal poles remove from each other, if the magnets are eaſily moveable, and the vortices between the poles act againſt each other. If the magnets *ab* and AB, fig. 14. Plate V. lie ſo far aſunder, that the vortices of their magnetick matters cannot mutually touch; the matter flowing around out of *b* goes into *a*, and the matter moving around out of B into A. But if they come ſo nigh each other, that the vortices between A and *a* mutually touch, the vortex at *h* muſt act againſt the vortex at *f*; and the vortex at *e* againſt that at *g*. By this reſiſtance the vortices at *he* and *fg* compreſs each other. And hereby both vortices become denſer, and therefore act with the greater force againſt each other. And ſo they muſt remove from each other, when brought mutually nigh, and when in a ſtate of eaſy mobility.

§. 281. But ſome parts may be eaſily forced off from the vortex at *h* by the vortex at *f*, and from the vortex at *g* ſome parts by the vortex at *e*, as alſo ſome parts from the vortex at *e* by the vortex at *g*, and ſome parts from the vortex at *f* by the vortex at *h*. So that ſome parts of the vortex at A go to *a*, and again ſome parts of the vortex at *a* to A. If the quantity of the particles carried off, which force alternately into each other out of the cognominal poles, is greater than the quantity of the particles, which reſiſt each other between the ſaid poles, two magnets muſt attract each other with their cognominal poles more than they repel.

§. 282. Iron, by means of a magnet, is thus made magnetical: The flexible particles, of whoſe diſpoſition and ſituation in a magnet its magnetick paſſages conſiſt, are already extant in the iron. If therefore you hold a ſmall piece of iron towards the emitting pole B of a magnet AB: As the matter ſtreams forth in large quantities with great velocity out of B, it muſt directly force into the iron at *a*, and burſt out at *b*, and conſequently from *a* to *b* form magnetick paſſages. And coming forth at *b*, it will be driven by the external magnetick matter, which encompaſſes the earth ſideways, and conſequently about the magnet quite to the pole A. And as therefore it forces into it again, ſo by the rule, by which one magnet unites with another, §. 278. it moves to the magnet BA. And thus *ab* is to be conſidered as a magnet ariſen, whoſe pole *a* is the ſame with the pole B. In like manner a ſmall piece of iron becomes a magnet at the abſorbing pole A, when laid hold on by its vortex, as it ſtreams quite through the piece of iron, and then in at A.

§. 283. From this it appears, that the vortex, which encompaſſes a magnet, expands itſelf by means of an iron, which is brought to one pole, through a larger ſpace.

§. 284. In like manner iron may turn magnetical by the earth's magnetick vortex only. This has been obſerved in iron bars, which for a long time have ſtood in a vertical poſition. Remarkable inſtances to this purpoſe the croſſes on the ſteeples at *Aix* and *Chartres* have afforded. Such bars turn in a ſhort time magnetical by the magnetick vortex of the earth, when their flexible parts are by an external cauſe brought into the diſpoſition or arrangement of the magnetick paſſages. This happens, if you heat an iron rod, or ſtrike it againſt a firm body, or hammer, or file, or bend it. This the remarks of M. *du Fay* on different experiments, made with the magnet, ſhew, and M. *Reaumur*'s experiments, that ſteel and iron become magnetick without touching. A peculiar method of making artificial magnets without a natural one, Mr. *Canton* publiſhed in *Engliſh* in 1751.

§. 285. But iron, by theſe very cauſes, loſes its magnetick virtue, when they change the poſition and arrangement of the flexible particles adapted thereto. We have inſtances, that magnetick needles have acquired an inverted direction by the violence of a flaſh of lightening, its north pole coming to be the ſouth.

§. 286. The arming of a magnet gives its vortical matter partly another direction, partly a ſtronger virtue. If the magnet is not encaſed or armed, the ſubtle matter diſſipates at its exit out of the pole B, fig. 16. Plate V. And thus too after a great degree of diſſipation it goes into the pole A. But if the magnet is encaſed, the the matter at the outlet and inlet will be brought cloſer together; as in the iron, on account of its eaſily moveable particles and adapted to its paſſage, it finds leſs reſiſtance, than in the external and elaſtick matter of the earth's magnetick vortex, when in immediate contact with the bare magnet. And thus it is collected into a denſe ſtream, which takes its way through the iron foot *b*, and on account of the reſiſtance, which the external matter of the earth's magnetick vortex cauſes, goes through *c* to the foot *a*, and with like denſity forces into its paſſages of eaſy opening. And with this denſity the magnetick virtue thus encreaſes. Its effect will be ſtill greater, if an iron be brought to both poles, and this laſt at the ſame time has ſuch poſition, as that one pole has as much to bear as the other. For, in this manner the external matter of the earth's magnetick vortex acts againſt the iron with a double preſſure.

PART VIII.

What Fluids have in common with Solids.

CHAP. I.

Of POROSITY.

§. 287. ALL bodies on the earth, which are viſible and tangible, are porous. In ſolids the pores are diſcovered partly by magnifying glaſſes; partly alſo hereby, that they may be penetrated by certain fluid matters. In fluids the poroſity ſhews itſelf by this, that they mutually penetrate each other, and mutually mix. Among the matters, that lodge in the pores of viſible bodies, air, fire, electrical and magnetick matters are the moſt known. A number of experiments, confirming the truth of this, we find in baron *Wolfius*'s *Uſeful Experiments*, P. I. c. 6. and P. III. c. 5.

CHAP. II.

Of Tranſparency, Opacity, and Viſibility.

§. 288. A Body is called tranſparent, when we can diſtinguiſh with the eye another body through it. And ſo the query is, how this is poſſible, as we cannot with good ground maintain, that the rays of light, as an actual matter, ſtream quite through each viſible body, as for inſtance, through glaſs, §. 207. The particles, of which the ſurface of a tranſparent body conſiſts, which gives no paſſage to the light, are compreſſed by the pulſes of the light, §. 211. If therefore the conſtituent parts of a body ſtand ſo connected among themſelves, that the compreſſion is propagated from one to the other ever in a right line; the eye may perceive through it another body.

A body, whoſe pores and interſtices contain matters in them, whoſe denſity differs far from the denſity of its parts, is leſs tranſparent, than when its pores and interſtices are filled with matters, whoſe denſity comes very near to the denſity of its parts. So paper has a greater degree of tranſparency, on drenching it in water or oil. In like manner a ſmall ſlice of an apple is tranſparent on filling its air-pores with water. The reaſon, that a body has ever leſs tranſparency the more the denſity of its parts differs from the denſity of the filling matter, conſiſts in this, that the incident rays of light are refracted otherwiſe in theſe matters than in its parts, §. 164. For, thus the compreſſion, produced by the pulſes of light, is not propagated in a right line, in which the light muſt fall into the eye, for a thing to be ſeen, §. 186. In like manner, a matter loſes ſomething of its tranſparency, when the poſition of its parts are ſo changed, that the action of the light cannot proceed as before in right lines. From this reaſon ice is more opaque than water. It is alſo white, as the light is reflected from it in greater plenty than from water.

§. 289. The motion of light to render a body viſible, muſt not only come into the eye, but alſo take its riſe from the body itſelf, or be excited.

§. 290. So that neither the perfectly tranſparent, nor the perfectly reflecting bodies are viſible. If a tranſparent body is called viſible, as for inſtance, water, the reaſon is, that it is opaque in ſome parts. But in ſo far as it is tranſparent, it is not at all viſible. A reflecting body gives the rays, which fall from another upon it, no motion, by which its pulſes are changed, but another direction only, that the pulſes take another courſe. As therefore reflected rays retain unchanged the ſpecies of their firſt motion; they can exhibit to the eye no other body than that, which the ſpecies of their motion firſt gave them. The ſmoother a mirrour, and the leſs thus there is wanting to it for the reflection, the leſs of its ſurface is viſible to the eye.

§. 291. And thus no body can be viſible, but a luminous body, §. 215. 289. Luminous bodies are of two ſorts. Some are luminous by their native force, and ſimply called luminous, as the ſun, or flame. Others are luminous by an adventitious force, and are naturally opaque, as the full moon. The adventitious force, whereby opaque bodies are luminous, is the force, with which the rays of another body act upon them. But in order to be made luminous by the action of the incident rays, the particles of their ſurfaces muſt come into a tremulous motion, whereby they excite in the contiguous light the pulſes, from whoſe propagation the rays of light ariſe, §. 214, 215, 216. If the parts of the ſurface of an opaque body re-acted only ſo on the incident rays, as to be only reflected, and thus acquire a different direction only; an opaque body would not make itſelf, but the other body, from which it received the incident rays, viſible to the eye, §. 289. The nature of the rays, by which an opaque body is ſeen, has therefore its origin in the tremor, or vibration of the ſmalleſt parts on its ſurface. The *Bolognian* ſtone is therefore luminous even in the dark, after having ſtood before in the ſun; as the tremor, excited by the rays of the ſun in its parts, ceaſes not directly, ſo ſoon as it is removed out of the ſun. But as this tremor or vibration is weaker than that of the ſmalleſt particles of a body luminous by its native force; ſo is alſo the luminouſneſs of an opaque body weaker. All this profeſſor *Euler* has deduced at large in his *Nova theoria lucis & Colorum*, c. 5.

CHAP. III.

Of the Colours of Bodies.

§. 292. THE ſeven colours, by which the ſeven ſpecies of the rays of light give themſelves to be known, §. 219. are called *ſimple*; as none of them are reſolvable into other colours, §. 220. And hence thoſe are called *compound* and *mixt*, which are reſolvable into the ſimple. Both ſorts of colours are obſervable in and upon fluids and ſolids, when the light falls from them into the eye. As the parts, which conſtitute the ſurface of an opaque body come into a tremor by the incident rays of light, §. 291. ſo in explaining the colours, with which the ſurface of an opaque body appears, we are to attend to the tenſion and elaſtick force of its particles.

§. 293. The red colour is produced in the light, when the ray of light, which excites it, oftener touches and ſtrikes the eye, than in an equal time any other ſimple ray does, §. 223. The ſurface of an opaque body, as of a roſe, for inſtance, appears therefore red, when its particles are ſo ſtretched, that as ſoon as they receive a ſtroke from an incident ray of light, they excite in the contiguous light in a ſecond ſo many pulſes and vibrations, as are neceſſary to form the red colour. In like manner an opaque body will appear under another ſimple colour, when the tremulous parts of its ſurface produce in the light, which is between it and the eye, in a ſecond the number of pulſes, which are required to this other colour. Were therefore the number of the pulſes known, which ſucceed each other in a ſecond in each ſimple ray of light; the production of the colours on the ſurfaces of opaque bodies would admit being explained with peculiar diſtinctneſs. But what number of pulſes follow each other in a ſecond, is pretty difficult to determine. For, the intenſity of a ray of light derives hence, that the following pulſe acts on the immediately preceding, §. 221. How ſmall therefore muſt the ſpace be between two pulſes, as each pulſe in a ſecond may be propagated through a length of 45 ſemidiameters of the earth, §. 207! How uncommonly great thus muſt be the number of the pulſes, which in each colour come to us in a ſecond!

§. 294. If the ſurface of a body conſiſts of mixt parts of different tenſion and elaſticity; they excite a mixt colour, when ſtirred up to vibrate by the incident light. For, differing in tenſion from each other, they muſt alſo differ in vibration. A ſtring vibrates ever quicker, or accompliſhes in a given time ever a greater number of vibrating motions, the tighter it is ſtretched. A particle on the ſurface of an illuminated body ſuppoſe to be called *a*, and the other *b*; and *a* in a ſecond to have twice the number of vibrating motions that *b* has: Thus *a* excites in the contiguous light twice as many pulſes in a ſecond, as *b* does. If *a* and *b* have on the ſurface the poſition, as that the excited pulſes in the light are blended together; the eye cannot diſtinguiſh from each other the greater number of pulſes of *a*, and the ſmaller number of pulſes of *b*. And therefore a mixt colour is perceived. In like manner, a mixt colour may appear, when the ſeveral parts of a ſurface are made vibratory by rubbing. And thus a coloured circle ariſes in the eye, as on a peacock's feather, if at the internal angle of the eye you move a finger up and down, and at the ſame time preſs the eye towards the external angle.

§. 295. As the ſeveral degrees of the different tenſion, which the particles of opaque matters may have, are unknown to us; we ſee the other reaſon, why we can give no diſtinct anſwer to the query, how it happens, that, for inſtance, one ſight has ever a different colour from the other, §. 293.

§. 296. But yet we would gradually proceed farther in judging of, and explaining the mixt colours, which take their riſe from the opake bodies, did we, 1. by means of priſms blend together in various manners the ſimple colours of the ſun's rays; 2. alſo combine together in a variety of ways the colours ariſing from the former. 3. Apply conſtant fixt names to all theſe compound colours: And 4. make a compariſon between the mixt colours of the ſun's rays, and the mixt colours of opaque bodies. For inſtance, a ray of the ſun forms on the wall of a darkened room a white circle, when incident through a narrow aperture, and proceeding unrefracted. Yet all the ſeven rays, which are called the ſimple, are blended in it. If therefore an opaque body, as ſnow for inſtance, exhibits ſuch a white colour, though not immediately enlightened by the ſun; I may affirm, that the vibrating particles of the ſnow, in the manner of the ſun, excite and mix the ſeven ſimple rays in the contiguous light.

§. 297. The brightneſs of a colour, as of red, for inſtance, is ever greater, the more intenſe the vibration, with which the particles of an opake and illuminated body act on the contiguous light. The cauſes of the intenſity of the vibration are to be ſought for, partly within and partly without it. The external cauſe is the force of the incident ray. And thus each colour appears more vivid in the light of the ſun than of the moon. To the internal cauſes belongs partly the tenſion, partly the ſubtlety of the particles.

§. 298. If a body in reſpect of certain parts is opake, but of the reſt, reflecting; it may exhibit two colours to the eye. Thoſe parts, which differ from the reflecting, are by the ſtroke of incident rays put into a vibration. And hereby they excite a colour proper to them. And thus poliſhed gold retains its yellow, and poliſhed copper its red colour. If, on the contrary, the ſtroke of the reflected rays, as in a metalline burning-mirrour, for inſtance, is ſo intenſe, that the eye can diſtinguiſh it from the ſtroke of the rays, which ariſe by the vibration of the opaque parts; it perceives in the image of the body, from which the reflected rays have taken their riſe, the colours alſo of the ſame body.

CHAP. IV.

Of SHADOW.

§. 299. SHADOW is a defect or privation of light, which a body undergoes, when between it and a luminous body an opake body interpoſes. Light is here taken for the motion, by which a body is rendred viſible; §. 144.

§. 300. In ſo far as the place, which the ſhadow covers, has at the ſides a certain degree of light, it is in ſome meaſure viſible. And in this ſenſe we ſay, that we ſee the ſhadow. But if the place has no light at the ſides, and by a perfectly opake body is entirely deprived of the light, which it might have from a luminous body; it is entirely darkened. And this defect or privation of light we call *pure* and *perfect ſhadow.*

§. 301. If an opake ſphere A, fig. 4. Plate VI. which is illuminated by a bigger S on the ſide obverted to it, projects a ſhadow; it has the form of a cone, whoſe baſe is in the leſs ſphere A. The ſhadow is contained between the rays CR and BR, which come from the luminous ſphere S, and paſs along the opake ſphere A. As the ſphere A is leſs than S; ſo the ſpace between the rays, which paſs along A, is leſs than that between the rays, which proceed from L and O. And therefore the rays ſhooting along A run together at length in the point R. If we imagine the leſs ſphere to be ſo cut in B and C, that the baſe of the ſection is a circle, through whoſe centre the line SAR goes, which is drawn through the centres S and A; the rays paſſing along the periphery of this circle form a cone, whoſe vortex is in R. So that the ſhadow is contained between rays, which form a cone, and conſequently is itſelf a cone.

§. 302. The axis of this cone, which the ſhadow of the leſs ſphere A, fig. 4. Plate VI. forms, is leſs than the diſtance of the vertex R of the cone from the centre of the ſphere A. The rays BR and CR, as right lines, cannot otherwiſe, touching the ſphere A, than form right angles with the ſemidiameters AB and AC. In the triangles ARB and ARC therefore the angles *u* and *x*, which RA forms with AB and

AC, are leſs than right angles. And conſequently, as well the arch EB, as alſo the arch EC is leſs than a quadrant. So that the right line BC, which is drawn from the point of contact B to the point of contact C, is leſs than the diameter of the ſmall ſphere QM. The centre *o* in the right line BC, which is the diameter of the baſe of the coniform ſhadow, is thus nigher the vertex of the cone than the centre A of the ſphere, which projects the ſhadow. And therefore *o*R, as the axis of the cone, is leſs than the diſtance of its vertex R from the centre A of the leſs ſphere.

§. 303. And thus in order to know the length of the ſhadow, which a ſphere, enlightened by a larger, projects; we muſt firſt calculate AR, as the diſtance of the centre of the ſphere from the vertex of the cone; and then A*o*, as the diſtance of the centre of the ſphere from the centre of the baſe of the cone. And then deducting A*o* from AR, *o*R the length of the cone remains. But if AR and *o*R differ inconſiderably; we may aſſume AR for the length of the ſhadow.

§. 304. AR the diſtance of the vertex of the conical ſhadow from the centre of the opake ſphere may be found as follows: Suppoſe SL to be the ſemidiameter of the greater and luminous ſphere, AB that of the leſs and ſhadow-projecting ſphere, and SA the diſtance of the centres

S and A from each other. If in the triangle SRL you ſet off from L to N the ſemidiameter AB of the leſs ſphere on SL the ſemidiameter of the greater; LN is = AB, and conſequently SN is the difference between both ſemidiameters. Suppoſe SL the baſe of the triangle SRL. As AB forms a right angle with BR at B, and SL with LR at L; AB and SL are mutually parallel. By the doctrine of triangles, in which a line is drawn parallel to their baſe, we may make the following concluſion. As SN the difference of both ſemidiameters of the ſpheres, to SA the diſtance of their centres from each other; ſo is AB the ſemidiameter of the ſhadow-projecting ſphere to AR the diſtance of its centre from the vertex of the coniform ſhadow. As ſuppoſe, for inſtance, SA = 12, AB = 2, and SL = 5. Then thus SN = 3, conſequently AR = 8; for 3 : 12 : : 2 : 8.

§. 305. And thus the nigher the opake ſphere comes to the luminous, the ſhorter the ſhadow: But the farther diſtant the opake ſphere from the luminous, the longer the ſhadow. As, if SA = 24; then AR = 16. For, 3 : 24 : : 2 : 16.

§. 306. Round the true ſhadow a certain mixture of light and ſhadow may ariſe. This is called the *penumbra*, or *half-ſhadow*. As, from the luminous ſphere, for inſtance, the ray LTV, fig. 4. Plate VI. paſſes from the point L along the ſurface of the opake ſphere at T. Between the rays OCR and LTV, indeed, a part of the luminous body is viſible; but a part, which is covered by a portion of the opake body, inviſible. On account of the covered and inviſible part there is a ſhadow in the ſpace between both the ſaid rays. On the contrary, it is mixed with the light, which comes from the viſible part. In like manner there is light and ſhadow mixed together in the ſpace between the rays OXZ and LBR. This half-ſhadow, or penumbra has alſo the form of a cone. But its vertex is in D between the luminous and opake ſpheres, and its baſe behind the dark part of this laſt. But as the cone TDX is fully enlightened; the penumbra exhibits properly a curtated cone TVXZ.

CHAP. V.

Of SOUND.

§. 307. NO ſound ariſes otherwiſe than by the ſtroke, which an elaſtick body either gives a reſiſting body, or receives from another. For, in order to excite ſound, either one ſolid muſt move againſt another, as a hammer againſt a bell; or, a ſolid againſt a fluid, as a ſtone againſt water; or a fluid againſt a ſolid, as the wind againſt a tree; or one fluid againſt another, as a flaſh of water againſt another flaſh; and by the motion act thereon, and thus ſtrike, §. 11. But the more elaſtick theſe bodies, the more adapted they are to excite ſound.

§. 308. If elaſtick bodies mutually ſtrike, they come to have a quivering or tremulous motion. A body has this tremor, when its parts ſtrike againſt each other, and vibrate. This vibration of the parts is to be diſtinguiſhed from that of the body, which the parts conſtitute. The body vibrates, when all its parts move ſo quick, as ſcarce to be diſtinguiſhable by the eye, §. 214. But if the parts of a body vibrate, they indeed come alike into motion, each alſo moves to and fro; but one ever to a different part from the other. And this happens even in the colliſion of elaſtick bodies. For, by the ſtroke, which an elaſtick body either gives or receives, its parts on the ſide, on which the ſtroke happens, are compreſſed; but again expanded, ſo ſoon as the ſtroke remits, §. 51. The compreſſed parts become indeed rarer, but broader and longer; as the inſtance of a blown bladder ſhews, on preſſing thereon with the flat hand. And neither breadth nor length can encreaſe, as that the contiguous parts ſhould not in like manner be compreſſed. Both happens towards different parts. And thus the ſingle parts come into motion towards different points. On the remiſſion of the ſtroke, the parts compreſſed thereby, ſpring back by virtue of their elaſticity. And this is done even by the parts, which moved towards different points from what the compreſſed parts did. And thus alſo the reſilition happens from different points. As the ſtroke acts with a certain degree of velocity, and the elaſtick parts are uncommonly ſmall they muſt neceſſarily fall into a vibratory motion. For, they move not only towards and from different points, but alſo, on account of their ſmallneſs, through unobſervably ſmall ſpaces. In both theſe properties the vibration of the parts of a body conſiſts. And therefore if an elaſtick body ſtrikes either againſt an obſtacle, or be it ſtruck on by a body, it will every time be put into a tremor.

§. 309. So that no ſound can ariſe in a body otherwiſe than by its quivering or tremulous motion. In ringing bells and ſounding ſtrings, their quivering or tremor is manifeſt to the touch.

§. 310. The tremulous motion, that gives riſe to ſound, paſſes through ſolid and opake bodies. Be a larum ſhut up ever ſo cloſe in a metal veſſel, yet it may ſtill be heard.

§. 311. But in order to become audible, the quivering, whereby it is excited, muſt be conveyed to the ear through the air. For, if a larum be ſet looſe in vacuo, no ſound can be perceived. On the contrary, the denſer the air about the larum, the louder its ſound.

§. 312. For the air to convey the tremor of a body to the ear, the air itſelf, interpoſed between the ear and body, muſt quiver, or be put into a tremulous motion. For, ſhould this air remain unſhaken, the vibrating parts of the tremulous body muſt either ſo part aſunder, as to reach the organ of hearing, or only compreſs, and propel the air between the body and ear, without the ſingle parts therein being put into a vibration. The firſt is inconſiſtent with the coheſion of the parts of a body: And a bell with the firſt ſound muſt be reſolved, and diſſipated in air. Happened the ſecond, we would perceive nothing more than either a preſſure of the air, or a wind in the ear. But in the ringing of bells we perceive neither preſſure nor wind, whether heard in a room, or on a free open place. If a wind is raiſed at the ſame time with the ſound, it ariſes from other cauſes than the quivering of the body. And we perceive the ſound, without any neceſſity of perceiving the wind, ariſen at the ſame time with it. That the quivering, which begins the ſound of a body, is excited in the contiguous air, may appear from a ſimple experiment: If of two uniſon ſtrings, diſtant a few feet aſunder, one be ſtruck on, or pulled, the other ſounds along with it.

§. 313. And thus without the air's quivering, or tremulous motion, no ſound is perceivable. Sound therefore always conſiſts in a quivering or tremor of the air. And alſo in what are called *water* and *glaſs hammers*, in which water along with rarified air is included, ſound ariſes; as the air, by means of the water, is quickly compreſſed in oppoſite directions: As Mr. *Eberhard* explains this in the appendix to his reflections on ſome points in natural philoſophy.

§. 314. And thus the intenſer the tremor of the air, or the greater the quantity of air, put into a tremor, the intenſer is the ſound. If, for inſtance, over one aperture of a hollow cylinder of metal a dried bladder is ſtretched; it will burſt with a loud crack by the preſſure of the air, on the cylinder with the other aperture ſtanding on the plate of the air-pump, and being exhauſted of air. The cauſe of the crack is the tremulous motion, which ariſes in the air; when, on the burſting of the bladder, it paſſes into the empty ſpace on the diſh of the air-pump and to the internal ſurface of the cylinder. But the purer the air is exhauſted, and the wider and taller the cylinder, the louder is the crack. For, then, a greater quantity of air is put into a tremor. In like manner the tremulous motion of the air produces a crack, when an exhauſted glaſs globe is thrown againſt a wall. The bigger the globe, the ſtronger it cracks in breaking.

§. 315. In the air a tremor, and conſequently a crack may ariſe, without the ſtroke or percuſſion of a ſolid, elaſtick and viſible body. A ſubtle matter, which may be inviſible, need only collect in the air to one place with the force to expel the air out of it, and with a great degree of quickneſs diffuſe itſelf at once, and hereby exhauſt or empty the occupied ſpace. For, ſo ſoon as this ſpace is exhauſted; the air, by virtue of its elaſticity, §. 114. forces in on all ſides to it. And thus the parts of the air with great velocity ſtrike from all ſides againſt each other. And thus a violent tremor ariſes. Electricity affords an inſtance to this purpoſe. You fill a glaſs globe with water, or with filings of metal, and ſet it in a metal veſſel, that with its rim goes ſomething over half the ſphere, and there ſtands a little way from its ſurface. On and over this globe let an electrick ſpark and flaſh be produced in the manner, which in 1746 in the treatiſe on the intenſity of the electrical force of water in glaſs veſſels I deſcribed §. 4. and exhibited Plate IX. So ſoon as the ſpark burſts forth, a ſnap ariſes, which comes near to the report of a piſtol in intenſeneſs. This ſpark is produced, ſo the electrical matter forces into the ſpace between the electrified body, and the unelectrified glaſs globe, and expels the air out of it, and at laſt inſtantly quits it. Into this exhauſted ſpace the air directly moves from every ſide, and is put into a tremor by the ſhock, with which the oppoſite moving parts act on each other. This tremor is encreaſed, ſo the disjoining electrical matter ſtrikes againſt the contiguous particles of the air.

§. 316. Sound propagates itſelf from the place of the body, where it is excited by its tremor, in a free ſpace, in the manner the rays of light do, Plate II. fig. 9, 15. in diverging lines: For, if a bell is ſtruck; its ſound is heard all around, ſo far as it extends.

§. 317. In a free ſpace therefore the intenſity of the ſound decreaſes, as the ſquare of the diſtance encreaſes. This may be ſhewn in the ſame manner, as was ſhewn, §. 145. of light; *viz.* that its intenſeneſs decreaſes in the ſaid ratio. If the place D, in which ſound ariſes in a body, be conſidered as a point in regard to the aperture of the ear, the diverging lines D E A, D F B, D G C, in which ſound is propagated, exhibits a cone. Were therefore the diameter of the aperture of the ear equal to the diameter E F, fig. 16. Plate II. in the cone D E F; the ear at G would receive four times as intenſe a ſound, as at C, were C twice as diſtant from D, as G is from D.

§. 318. If the lines, in which ſound is propagated from a number of bodies ſounding at once, interſect each other in the ear, how they will; yet we can diſtinguiſh the ſound of each ſeveral body from the ſound of the others, ſo the intenſeneſs of the one ſound render undiſtinguiſhable, or drown not, the weaker; or the ſmall intermediate ſpace between bodies ſounding at once cauſes no confuſion of the ſound. The aperture of the ear is in this caſe, where a number of bodies ſounding together are without it, to be conſidered as a point in reſpect to the ſurface, in which they have their places. Now ſo the diverging lines, along which ſound takes its courſe, interſect in the ear; they will again diverge behind this point, and ſtrike the internal ſurface of the ear in different points. So that every ſound is perceived in a peculiar point, from which to the point, where it took its riſe, a right line may be drawn. Now if the places of the ſonorous bodies be ſo near each other, that the lines drawn from them to the aperture of the ear, mutually touch on its internal ſurface; the ſtrokes and pulſes of theſe prove as little diſtinguiſhable from each other, as the pulſes of light, which mix with each other in the

the eye, when the intermediate ſpace of two luminous bodies is obſervable under an infinitely ſmall angle.

§. 319. Sound propagates itſelf far more ſlowly than light, or the effect of a luminous body. And thus we obſerve the flaſh of a cannon before we hear its report. Attempts have been made to diſcover the velocity of ſound, or the ſpace ſound paſſes over in a ſecond: But it has been found, to be greater at one time than another. In *Italy* ſound runs over 1185 *Paris* feet in a ſecond; in *France* 1172; in *England* 1072; In *America* at *Cayenne* 1098, and at the town of *Quito* 1050. And tho' we aſſume the greateſt of theſe numbers, yet the velocity of ſound to that of light, whoſe effect paſſes in a ſecond through 45 ſemidiameters of the earth, §. 207. 293. is conſiderably ſmall. How by means of ſound to meaſure the diſtance of a place, M. *Melderkreutz* ſhews in the *Swediſh* acts, T. 3. p. 82.

§. 320. A ſound is called a tone, on conſidering at the ſame time another ſound, and comparing together in both the velocities of the vibration in the parts of the tremulous air. Theſe velocities are eſtimated by the velocities of the vibration of two ſtretched ſtrings. If the one vibrates quicker or oftener in a limited time, and the other ſlower, or ſeldomer in the ſame time;

the tone of that vibrating quicker is called *high*; and of the other vibrating ſlower, *deep* or low. In the velocity, with which two ſtrings vibrate, we are to conſider their length, tenſion, and thickneſs. If two ſtrings A and B are ſtrung equally tight, and are equally thick, and A ſhorter than B; the ſhorter A vibrates quicker, and thus gives a higher tone than B. If two ſtrings A and B are ſtrung equally tight, and are equally long, and A the more ſlender than B; the more ſlender vibrates quicker, and conſequently gives a higher tone, than the thicker B. For, the thicker a body, the more it reſiſts the motion from the quantity of its matter. If two ſtrings A and B are equally long, and equally thick, and A tighter ſtrung than B; the tighter ſtring A yields a higher tone than the ſlacker ſtring B. What has been ſaid of the ſtrings, may be properly applied to other elaſtick bodies, on conſidering each of them, as conſiſting of pure ſtretched ſtrings.

§. 321. Hitherto we have conſidered ſound, in ſo far as it is propagated ſtraight onwards, proceeding from the place of its riſe in diverging lines, §. 316. But if the parts of the tremulous air ſtrike on a fixed and immoveable matter, they excite by their reſilition, §. 78. 114. a *reflected* and *echoed ſound*.

§. 322. By the reflection a ſound may be now conveyed with unchanged intenſity to a diſtant place, again heightened, and again weakened. At a diſtant place it may be perceived unchanged, on taking its way through a cloſe confined paſſage, both whoſe apertures are equally wide, its ſides ſmooth, and its cavity of ſuch elaſticity and form, as to allow the tremor of the air to force with equal intenſeneſs to the other aperture. If ſuch a cloſe paſſage is internally ſo wide throughout, as it is at both the apertures; the tremors of the air are not weakened by a diſſipation either in its internal compaſs, or at the exit, where you incline to perceive the ſound. If, indeed, the cavity of the paſſage is internally wider than at both the apertures, but having an elliptick figure, by which the tremors of the particles of the air at firſt diſſipated, are again collected, and at the exit brought into ſo narrow a ſpace, as is that at the entrance where the ſound was excited; it can in like manner be no weaker at the outlet than it was at the inlet. Echoing vaults are an inſtance. And as an inſtance of equally wide paſſages, through which ſound takes its courſe unimpaired, *Kircher* adduces the *Roman* aqueducts, between 500 and 600 feet long; where one may hear at one end, what another ſpeaks at the other.

Sound is weakened by the reflection, when the matters, from which it is to reflect, are little elaſtick; as we obſerve in rooms and buildings, where either the walls are hung with ſoft tapeſtry, or a great number of men is preſent.

Sound is heightened by the reflection, when the tremors of the air are thereby either multiplied, or conveyed out of a wider into a narrower ſpace. The firſt happens in ſpeaking-trumpets, the other in acouſtick tubes. But in general the heightening, which a ſound acquires by the reflection, whether happening in rooms, or inſtruments, is called the *Reſonance.*

§. 323. If a body, that reflects the ſound, is ſo diſtant, that the reflected ſound may be perceived at the place, where the original is perceived, on the ſenſation of the original having ceaſed; this reflected ſound is called the *Echo.*

§. 324. One ſound may be very plainly diſtinguiſhed from another, if from the beginning of the one to the beginning of the other a ſecond intervenes. If therefore a ſpeaking perſon is 536 *Paris* feet diſtant from the place, that reflects the received ſound; he may by the echo or reflection hear each ſeveral ſound in particular, on intermitting for a ſecond every time to begin the following. For, as a ſound in a ſecond paſſes over 1072 feet, §. 319. a ſingle ſound comes from the place of its riſe in half a ſecond to the reflecting place, ſo the diſtance between both places amount to 536 feet; and back again in half a ſecond from the reflecting place to the firſt.

§. 325. If therefore a word, that conſiſts of a number of ſingle ſounds or ſyllables, is pronounced ſo quick, that the ſingle ſounds ſucceed each other in a ſhorter time than in a ſecond; and you wait a ſecond after ending the word, before you begin the following; the echo gives the laſt ſyllable only of the finiſhed word to be perceived. And if one pronounces a number of words ſo quick upon each other, that the time between two is ſhorter than a ſecond; the ear by the echo perceives the laſt ſyllable only of the laſt word.

§. 326. A muſical ear takes, to diſtinguiſh ſuch tones, as follow on each other, a much ſhorter time than a ſecond. And ſo an expert violiniſt may in a ſecond produce and diſtinguiſh nine tones one after another on the violin. Such a perſon may thus obſerve an echo, when ſo diſtant only from the reflecting place, that the original ſound takes $\frac{1}{9}$ of a ſecond only, to move thither and back again. The diſtance between the reflecting place, and the place of the original ſound would amount to about ſixty feet. For $\frac{1}{9}$ of 1072 makes 119. So far would the ſound in $\frac{1}{9}$ ſecond be propagated from the place of its riſe. And therefore in order to hear the echo again at the place of its riſe in $\frac{1}{9}$ ſecond; the reflecting place, which gives the echo, need be diſtant from the place of its riſe about ſixty feet only, as the half of 119.

§. 327. So many times ſixty feet therefore as the diſtance from the ſpeaking to the reflecting place amounts to, ſo many ſingle tones one after another would the echo bring back in a ſecond. Such an echo is called *polyſyllabical.* If it returns one and the ſame ſound a number of times, it is called *polyphonous.* This laſt ariſes, when many reflecting bodies are by or above each other at different diſtances from the place of the original ſound. *Gaſſendi* in his remarks on *Diogenes Laertius*, Book X. relates, that *Boiſſard* heard the verſe,

Arma virumque cano, Trojæ qui primus ab oris.

reflected eight times at the monument of the *Metelli* not far from *Rome.* Extraordinary effects of an echo are deſcribed in the memoirs of the academy of ſciences for the year 1692, p. 94, 95, 96.

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